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1. Your reference	PF36	
2. Patent application number *(The Patent Office will fill in this part)*	0301136.8	20 JAN 2003
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	Polatis Limited 25 Cambridge Science Park Milton Road Cambridge CB4 0FW	
Patents ADP number *(if you know it)*	8105488001	
If the applicant is a corporate body, give the country/state of its incorporation	United Kingdom	
4. Title of the invention	OPTICAL CONNECTOR	
5. Name of your agent *(if you have one)*	i.p.21 Limited	
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	Norwich Research Park Colney NORWICH NR4 7UT	
Patents ADP number *(if you know it)*	8060758001	

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8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body.* *See note (d))*	YES

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Description	23
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DUPLICATE

OPTICAL CONNECTOR

Field of the Invention

The invention relates to an optical connector and an optical connector arrangement for use in a fibre-optic communications system, an optical network section comprising an optical connector and a method of increasing the functionality of an optical network using an optical connector.

Background of the Invention

One of the major problems in designing optical networks is in the placement of the optical components, such as Optical Add Drop Multiplexers (OADMs), optical switches, amplifiers, equalisers and dispersion-compensating elements. Design decisions on the inclusion and placement of such elements need to accommodate not only the initial traffic on the network, but also future network growth, which is often unpredictable. This issue is especially critical for Metropolitan (or city) networks where cost needs to be minimised and growth is especially unpredictable.

The normal approach to the problem is to include enough elements initially to accommodate currently foreseen traffic growth, and to take a part of the network out of commission where additional upgrade needs to be accommodated. This is difficult to do while minimising impact on existing

traffic, and is a major operational expense. Taking part of a network out of commission may involve truck-rolling and splicing a new network element into the existing network as and when required. This involves a heavy operational cost and can mean the network ring or line system is out of commission for hours at a time. A second alternative is to install an in-line connector into the network where it is thought that a future upgrade may be required and then truck-roll and connect a new element when it is actually needed. This also incurs a high operational cost, though the "down time" involved is less than in the previously mentioned case (tens of minutes instead of hours). Finally (see Figure 1), it is possible to install a 2 x 2 optical switch where the future upgrade may be required, the switch being operated to include the new element in circuit when the need actually arises. While this is fast (< 10ms is normally required for such switching), the reliability is lower and there are higher losses, since two passes of the signal occur and in addition two connectors are involved. Furthermore, most such switches require a source of power and will increase the first-in cost of the network.

Summary of the Invention

In accordance with a first aspect of the invention there is provided an optical connector having first and second connector-portions, the first connector-portion comprising first and second optical guides for respectively receiving and transmitting first and second optical radiations, and a first, total internal reflection surface upon which, in use, the first optical radiation impinges; the second connector-portion comprising a second surface for placing against said first surface thereby to frustrate the total internal reflection function of said first surface, the second connector-portion being associated in use with an optical element;

the optical connector being adapted for two modes of use:

- a first mode, which excludes the second connector-portion and in which the first connector-portion is inserted in a first optical-fibre arrangement having a given functionality and the first surface reflects the first optical radiation into the second optical guide, and

- a second mode, in which the connector-portions are mated together such that the second surface is held firmly against the first surface and accurately aligned therewith, thereby frustrating said total internal reflection and allowing the optical radiation from the first optical guide to pass through to the second connector-portion and interact with the optical element, whereby the functionality of the optical-fibre arrangement is increased.

In a second aspect of the invention an optical connector arrangement is provided, which comprises an optical connector as described under the aforesaid first aspect and wherein each first connector-portion comprises a plurality of pairs of first and second optical guides. Alternatively, the connectors may be arranged as an array.

In accordance with a third aspect of the invention an optical connector is provided, having first and second connector-portions,

the first connector-portion comprising a first optical guide for carrying optical radiations from a first optical fibre, a first, total internal reflection surface upon which, in use, said radiations impinge, and a means for enhancing an eye-safe operation of the optical connector; the second connector-portion comprising a second optical guide for carrying optical radiations to a second optical fibre and a second surface for placing against the first surface thereby to frustrate the total internal reflection function of said first surface;

the optical connector being adapted for two modes of use:

- a first mode, in which the first and second connector-portions are mated together such that the second surface is held firmly against the first surface and accurately aligned therewith, thereby frustrating said total internal reflection and allowing the optical radiations from the first optical guide to pass through to the second optical guide, and
- a second mode, in which the first and second connector-portions are separated, so that the radiations in the first optical guide are reflected by the first surface into the means for enhancing an eye-safe operation, whereby the eye-safe operation of the first connector-portion can be enhanced.

Under a fourth aspect, the invention provides a method of increasing the functionality of an optical network by the addition of an optical element, comprising; equipping the network with the first connector-portion of an optical connector as claimed in any one of Claims 1 to 18; connecting the optical element to the second connector-portion of the optical connector, and mating together the first and second connector-portions.

The invention further provides in a fifth aspect thereof a method of upgrading dispersion control in a network, comprising: equipping the network with the first connector-portion of an optical connector as claimed in Claim 1; equipping the second connector-portion of the optical connector with a tap coupler; connecting dispersion-measurement apparatus to the tap coupler to determine the value of dispersion slope compensation required; removing the tap coupler from the second connector-portion, and connecting to the second connector-portion a dispersion slope compensation module (DSCM) having the determined compensation value.

In a sixth aspect of the invention an optical connector device is provided for mating with a corresponding optical connector device having a total-internal-reflection frustrating mating surface and associated, in use, with an optical element, the optical connector device comprising first and second optical guides for respectively receiving and transmitting first and second optical radiations, and a total internal reflection surface upon which, in use, the first optical radiation impinges and against which the mating surface of the corresponding optical connector device can be firmly held.

Realisations of the optical connector, optical connector arrangement and optical connector device are set forth in the dependent claims.

<u>Brief Description of the Drawings</u>

Embodiments of the invention will now be described, by way of non-limiting example only, with the aid of the drawings, of which:

Figure 1 is a prior-art solution to the problem of upgrading existing fibre networks;

Figures 2a, 2b and 2c show three different phases in the use of an optical connector according to the invention in a first embodiment thereof;

Figure 3 illustrates the basic modes of use of an optical connector in accordance with the invention;

Figure 4 is a diagram showing a second embodiment of a first connector-portion of an optical connector according to the invention;

Figure 5 is a diagram showing the embodiment of Figure 4 in its "mated" (second mode of use) state;

Figures 6a, 6b, and 6c illustrate a variant version of the second embodiment;

Figure 7 shows a further variant version of the second embodiment;

Figure 8 is a diagram of a third embodiment of an optical connector in accordance with the invention;

Figure 9 is a diagram of a fourth embodiment of an optical connector in accordance with the invention;

Figures 10a and 10b are diagrams of a fifth embodiment of an optical connector in accordance with the invention;

Figure 11 is a diagram of a sixth embodiment of an optical connector in accordance with the invention;

Figure 12 is a diagram of a seventh embodiment of an optical connector in accordance with the invention;

Figure 13 is a diagram of the seventh embodiment in a first version of its "mated" (second mode of use) state;

Figure 14 is a diagram of the seventh embodiment in a second version of its "mated" (second mode of use) state;

Figure 15 is a diagram of the seventh embodiment in a third version of its "mated" (second mode of use) state;

Figure 16 is a diagram of the seventh embodiment in a fourth version of its "mated" (second mode of use) state;

Figure 17 illustrates a first optical-connector arrangement involving multiple optical guides;

Figure 18 illustrates a second optical-connector arrangement involving multiple optical guides;

Figure 19 is a diagram of the first embodiment of an optical connector in its first mode of use in accordance with the invention in a moisture-resistant form;

Figures 20, 21a and 21b are respective versions of the moisture-resistant optical connector of Figure 19 in its second mode of use;

Figure 22 is a version of a moisture resistant connector with a second dissimilar mating connector shown

Figure 23 is a diagram illustrating a cascaded arrangement of optical connectors under the invention;

Figure 24 shows an optical connector according to the invention in an eighth embodiment thereof;

Figure 25 shows a known method of implementing an Optical Add-Drop Multiplexer (OADM) in a network

Figures 26 to 32 show various applications in which the optical connector according to the invention may be employed; .

Figure 33 shows a backplane implementation of an optical-connector arrangement involving optical connectors in accordance with the invention;

Figures 34a and 34b are diagrams showing the use of an optical connector according to the invention in the first embodiment thereof as an eye-safe connector;

Figure 35 shows a variant version of the eye-safe connector of Figure 34 in its first mode of use, and

Figures 36a and 36b are diagrams illustrating a further embodiment of an eye-safe optical connector according to the invention.

Detailed Description of Embodiments of the Invention

In a first embodiment of the invention an optical connector is provided which is divided into two portions. Figure 2a shows a first portion of the connector comprising a body 10 which accommodates first and second optical guides 12, 14, each of which connects at one end to a refractive element 16 by way of respective collimators 18, 20 which, in the illustrated embodiment, is a

graded-index lens (a "GRIN"). Also included in the body 10 are two or more alignment apertures 22 for the accurate alignment of a second portion of the optical connector (see Figure 2b).

The operation of the first connector-portion in a first mode of use of the connector depends on the presence of an airgap (or low index medium or vacuum) at a face 24 of the refractive element 16 and, in order to protect this refractive-element/airgap interface from fouling, a protective cover 26 is preferably affixed thereto by some suitable method. which will be readily apparent to the person skilled in the art of optical connector design.

In the afore-mentioned first mode of use of the connector, in which the first connector-portion is separated from the second connector-portion, an optical signal input at Port 1 of the first connector-portion will undergo total internal reflection at the glass-air interface 24 and exit from Port 2. Thus, where for example the first connector-portion is included in a network ring, the signal transmitted to Port 2 will be available for use elsewhere in the ring.

Assuming now that the ring is to be extended – in the manner of a retrofit - by the addition of some kind of optical element (e.g. an add/drop multiplexer), the protective cover or film 26, where one is supplied, is removed and a second connector-portion substantially identical to the first is offered up to the first connector-portion and aligned using alignment pins 28 or similar, which are inserted into the apertures 22 (see Figure 2b). This second connector-portion also has a refractive element, shown as element 30 in Figure 2b, but in this case this element has, in a preferred realisation, an index-matching material coating an external face of the refractive element 30. This second connector-portion is offered up to the first connector-portion until only a very small airgap still exists between the total internal reflection surface 24 and the material (e.g. of the order of 50 microns). Then, in a process which takes much less than 10ms (in practice < 1ms), the second connector-portion is pushed all the way towards the first connector-portion until the two opposing surfaces of the refractive elements 16, 30 are in firm contact with each other (Figure 2c). This firm contact, assisted by the presence of the matching

material, ensures that no internal reflection takes place in the first connector-portion and consequently the optical signal at Port 1 is passed through into the refractive element 30 and on into the optical guide 30 and out through Port 4. Likewise, a signal which enters the second connector-portion at Port 3 is passed on to the optical guide 14 and out through Port 2. . To ensure that optical crosstalk in the mated connector is desirably less than –50dB between ports 1 and 2, the index matching material should typically be within 0.2% of the index of the refractive element.

The mating of the two connector-portions constitutes a second mode of use of the connector, in which an optical element is brought into play in the network which was not present before. This introduction of a new optical element, which is connected to Ports 3 and 4, is achieved with acceptably low loss, causes minimal interruption of traffic and can be provisioned at very low cost, in contrast to the known conventional methods of extending an optical network described earlier .

The process set forth above is summarised in outline form in Figure3.. Figure 3 shows part of an optical network ring 40 containing the connector first portion 42. An optical signal 44 passes through the first connector-portion 42 and on to the rest of the ring. This is the first mode of use of the connector. In the second mode, the first connector-portion 42 is mated with a second connector-portion 46, which is installed in a second optical-fibre arrangement 48 feeding an optical element 50. Due to the frustration of the internal reflection process in the first connector-portion by the presence of the second connector-portion, the signal 44 passes into the optical element 50 via the optical fibre 48. Thus the ring 40 is extended by the addition of the optical element 50, again with minimal interruption to the live traffic on the network..

A second embodiment of the optical connector according to the invention is shown in its first mode of use in Figure 4. In this embodiment, a ferrule 60 is attached to a connector body housing 62, which accommodates normal items such as spring contacts, a latching mechanism and a form of strain relief. The

ferrule contains first and second optical-signal guides, i.e. lengths of optical fibre 64, 66, which – as in the first embodiment – feed into a collimator element 68 such as a GRIN lens, the collimators leading into a refractive element 70, on two walls 72 and 74 of which a reflecting means 76, 78 is provided. These reflecting means may take the form of a local airgap or gap filled with some other low-index medium or a vacuum or a reflecting surface applied to the outside of the surfaces 72, 74.

The use of these reflecting means allows the fibres 64, 66 from Port 1 and Port 2 (not shown) to exit from the connector housing 62 substantially parallel to one another. This has a number of advantages in fabrication and use, due to the fact that the connector can then employ construction technologies which are commonly used with standard fibre-optic connectors. Figure 5 shows two such connector-portions mated together in the second mode of use using a receptacle 80, which aligns the connector-portions correctly.

A similar arrangement is shown in Figure 6a, but incorporating two additional features. The first feature is that one or both front surfaces of the connector-portions is polished to create a slight curvature in the mating surfaces, e.g. of the order of 20 mm radius, which is common in FC/PC fibre-optic connectors. Now when the connector-portions are mated, the closure force flattens the end of the connector-portion(s) slightly so as to ensure a very good physical contact over the centre of the mating surface. Typically, the connection force may be around 1 kg and the glass would be flatted over an area of around 250 microns diameter.

The second feature is the inclusion of a snap-closure mechanism, such as a Belville™ washer just in front of one of the surfaces to be mated. This is best achieved by inserting the first connector-portion ferrule into the aligning receptacle (e.g. a bulkhead connector mount) from one end and then inserting the washer into the receptacle from the other end until it touches the outer periphery of the total internal reflecting surface of the first connector-portion. Finally, the second connector-portion is inserted from the second end of the receptacle and pushed in until the mating surface of the second connector-

portion just touches the Belville™ washer at its outer face (see Figure 6b). The curvature in the washer automatically ensures a suitable minimum spacing (10-100 microns) between the two mating surfaces. Further pressure on the second connector-portion forces the washer to yield and flatten and, since the washer only occupies an outer part of the total internal reflecting surface of the first connector-portion which is less protrusive than the inner part (see Figure 6c), the two mating surfaces can be brought together successfully. (There may be a more compliant spring at the back of the connector housing which can easily extend by the 10- 100 micron distance without a significant reduction in force.)

It is stressed that the Belville™ washer feature is not a requirement where a curved mating surface is used, but only an enhancement, allowing as it does an improved speed and control of the final closure of the connector-portion pair.

Instead of providing a continuous curvature on one or both of the mating surfaces, a stepped surface configuration (not shown) may be employed, whereby a flat, or even curved, mating surface gives way to a recess in which the washer sits, the recess of course being of such a depth that the washer is still able to perform its distancing function vis-à-vis the opposing mating surface.

Figure 7 shows an alternative arrangement of the second embodiment, in which alignment is achieved using a pair of alignment pins instead of a bulkhead. The figure shows a mated pair of such connector-portions.

A third embodiment of the optical connector according to the invention is illustrated in Figure 8. This shows a curved refractive element 82, which performs the same reflective functions as the element shown in Figures 4 and 5, but in addition uses its curved surface to perform the collimation and focussing operations.

In a fourth embodiment, shown in Figure 9, a Graded Index (GRIN) Lens 84 is employed to perform both the focussing and beam deflection functions.

This is preferably a high aperture GRIN, with a numerical aperture of approximately 0.6, with, for example an index of 1.468 at the radius where the fiber cores are attached (SMF28 fiber), thereby minimising back reflection, and an index of 1.85 at the centre, giving a beam incidence angle of ~35 degrees to the normal. This comfortably exceeds the critical angle of 32 degrees between the high index material and air.

Figure 10a shows a fifth embodiment incorporating a ball lens 86 with a polished mating surface 87. This lens is used to perform the deflection and collimation functions by refraction at the curved interface. Figure 10b shows typical design parameters for a range of lens refractive indices between 1.5 and 2.2. Preferably, the curved surface is anti-reflection coated to maximise transmission at the designed angle of incidence.

Figure 11 shows a sixth embodiment incorporating an optical waveguide structure 90 on an optical substrate 92 (e.g. silica-on-silicon waveguides or ion-exchanged waveguides). The structure, which comprises two individual waveguides 94, 96, compels the optical radiation to/from the total internal reflection surface to meet at a point 98 on that surface.

A seventh embodiment of the optical connector according to the invention is illustrated in Figure 12, which shows a prismatic element 100 attached to the end of a ferrule 102 accommodating the optical guides 104, 106 in combination with respective collimating means 108, 110, which again may consist of a GRIN lens. The prismatic element 100 provides two reflective interfaces 112, 114 which, in the first mode of use of the connector-portion, cause total internal reflection of the incident optical radiation from input to output.

Figure 13 shows a pair of such connector-portions mated in a quasi-collinear fashion using a suitable receptacle, e.g. a bulkhead connector mount 118. Here the optical radiation in the optical guide 104 is reflected twice by the two prismatic elements and enters the optical guide 119 to feed an optical element coupled to the second connector-portion, the optical radiation returned by the

optical element then entering the optical guide 116, from where it passes from the second prismatic element 120 into the first prismatic element 100 and out through optical guide 106.

Figure 14 shows an alternative version of the same arrangement where the two connector-portions are mated at an angle close to 90°. This arrangement can have advantages in telecommunications equipment, since it reduces the space needed to accommodate fibre-bend radii by providing a "corner reflector" function. The optical-signal paths are as shown by the arrows.

Figure 15 shows yet another alternative version of the same arrangement, but this time exploits the fact that there are two reflecting surfaces in the prismatic element employed, such that two independent connector-portions 132, 134 can be mated with the first connector-portion 130. This arrangement has the advantage that, although it provides the function of two connectors, the through-loss in the unconnected state (first mode of use) of the first connector-portion 130 is that of a single connector only. The optical-signal paths are again shown by the arrows.

Figure 16 shows the previous arrangement with a fourth connector-portion added. This arrangement couples connector-portion 130 to connector-portion 136, while simultaneously disconnecting connector-portion 130 from connector-portions 132 and 134. Thus this offers a different range of upgrade capabilities to network operators, replacing the upgrade option offered by connector-portions 132 and 134 by that offered by connector-portion 136. In the state shown it is even possible to arrange for connector-portions 132, 134 to pass their own optical signals completely independently of those being passed by connector-portions 130 and 136.

Figure 17 shows an optical-connector arrangement, in which a connector-portion contains a number of pairs of optical guides (fibres) arranged in parallel, the number shown being three pairs with one central fibre. Due to the symmetry of the structure, it is possible to arrange the seven fibres shown along the centre of the ferrule with a high degree of accuracy. In the example

shown fibre 1 is paired with fibre 2, fibre 3 is paired with fibre 4, and fibre 5 is paired with fibre 6. The centre fibre 7 operates as a standard "straight through" connector, which could be useful in monitoring closure of the connector This arrangement has the benefit that multiple connections can be simultaneously made by sharing the same mating aperture. It should be apparent that a different number of pairs of fibres may be similarly arranged by changing the diameter of the centre fibre and, further, this feature can be used in combination with any of the parallel-beam collimation and redirection methods described heretofore (cf figs 4-10).

Figure 18 shows an alternative multi-fibre arrangement. In this arrangement, two arrays of fibres are aligned vertically one above another, and pairs of fibres are associated with respective connector-portions. Preferably, this is constructed by using two arrays of fibres mounted in alignment grooves in a substrate such as silicon or plastic, the two arrays then being vertically aligned relative to each other in order to achieve fibre pairings. An array of optical elements used for the reflection and focussing functions may be formed using any of the optical devices shown in Figures 2 and 4-16 and incorporating or omitting, as desired, the curved mating-surface arrangement shown in Figures 6a and 6b.

Advantageously, in such multi-fibre connector arrangements, the action of mating connectors will disconnect some pairs of fibres, while simultaneously mating other pairs of fibres. This will have a number of network applications.

Moisture ingress or condensation is a possible issue with the connectors previously described. This is because a film of water (or other contaminant) on the mating face could destroy the total internal reflection required for the use of the connector in the unmated state. A simple solution is to use a moisture-tight cap on the end of the first connector-portion, thereby retaining the air gap, or by the provision of a single-use sacrificial protective layer, as shown in Figure 2a. However, this approach may be deemed unreliable in some applications, and it does not permit the end-face (mating surface) of the connector-portion to be cleaned without disrupting the total internal reflection.

In addition, once the protective layer or end-cap is removed, condensation may form on the end of the connector, disrupting the total internal reflection, and thus increasing the loss of the connector and destroying the inherent eye-safe property of the connector (see later).

A moisture-resistant first connector-portion is shown in Figure 19. This incorporates a thin block of glass of substantially the same index as the prism shown, retained by a flexible membrane which holds it a few microns offset from the prism surface, and which also acts as a hermetic seal. When two such connectors are mated, the flexible membrane is deformed allowing both thin glass blocks to contact the prisms and each other, as shown in Figure 20, thus allowing the optical signals to pass through to the opposing optical guides. This connector therefore has the advantage of being moisture-resistant, and also permitting easy cleaning without disrupting the total internal reflection when in the unmated state.

As shown in Figure 20, there will be a lateral offset σ of the beams in the straight-through state (second mode of use), which may cause undesirable optical loss. This loss can be minimised by making the glass thickness small relative to the beam diameter. Alternatively, the connections on one half of the mating connector can be offset in order to minimise through-loss, at the expense of loss in the unmated state, as shown in Figure 21a. In this figure the collimators 140, 142 have been displaced by a distance γ from the centrelines 144, 146 of the prism faces 148, 150, respectively, so that the converging optical radiation 152 on the normally total internally reflecting surface of the first connector-portion is directly aligned with the radiation-axes of the collimators 140, 142.

In many applications, the unmated loss of the second connector-portion is not important. Indeed, in some applications it is desirable to have high isolation between ports 3 and 4 in the unmated state. An example of such an application is where the second connector-portion feeds an optical amplifier, which in the unmated state could induce laser modes if internal reflection occurs at the outer-facing surface of the prism 150. High isolation can be

achieved by choosing the thickness of the intervening glass layers such as to ensure that the resulting design offset of the collimated beams from ports 3 and 4 is sufficient to achieve high isolation in the unmated state (an approximate figure for the offset γ is 4 times the beam diameter). A refinement of this concept is shown in Figure 21b where collimating means 147, 149 are placed adjacent and parallel to port 3 and to port 4 to create a connection in the unmated state to new ports 5 and 6 respectively. In a network application, for example, this may be of benefit in enabling connection of an item of test equipment to ports 5 and 6, which then is able to measure parameters of the optical element on ports 3 and 4 in the unmated state of the connector. When, however, the second connector-portion is mated with the first connector-portion, the test equipment will automatically be disconnected from the network element due to the removal of the total internal reflection at the mating surface of the second connector-portion.

Figure 22 shows a preferred embodiment of a moisture-resistant optical connector. The first connector-portion on the left is moisture-resistant. It has a thin membrane of index-matched glass (e.g. 20 microns thick) spaced from the total internal reflection surface 152 by, for example, 10 microns and hermetically enclosing a compressible, non-condensing, low-index medium such as dry nitrogen. The right-hand connector-portion is not moisture-resistant, and has a curved surface 154 of, for example, 10 mm radius. When these two connector-portions are closed, the rounded surface of the second connector-portion forces the glass membrane against the surface 152, thereby coupling the optical signal to ports 3 and 4.

To minimise levels of cross coupling in the mated state, the mating surface of the glass block membrane can be at a small angle to the internal TIR surface (figs 19,20,21). Alternatively or in addition, cross coupling and loss in the mated state may be reduced by the addition of a small amount of index-matched fluid to the mating surface prior to connection. This does not affect the TIR prior to connection, as this happens internally to the connector (see Figures 19-22)

An alternative design of moisture-resistant connector is to select the refractive index of the first connector-portion end-face to be such that total internal reflection will still occur even when this end-face is coated with moisture. An example of a suitable material for this purpose is TiO_2 (rutile), having a refractive index of around 2.2. It should be noted that, where materials of dissimilar refractive indices are used, antireflection coatings may be employed to reduce losses where required.

Multi-Path Interference (MPI) can occur when an optical signal can be split into two paths and then recombined. In a number of applications, MPI needs to be kept very low – example, the interfering signal needs to be 50 dB lower in magnitude than the main signal. When the connector according to the invention couples in an optical element, as in Figure 2, residual reflectivity within the connector in the mated state can constitute an interfering signal. Figure 23 shows a method of cascading two connectors according to the invention to double the MPI rejection. In the unmated state the signal takes the path Port 1 – Port 2 – Port 1A – Port 2A, undergoing total internal reflection twice. The network element 160 is connected from Port 4 to Port 3A. In the mated case, the main path is Port 1 – Port 4 – network element - Port 3A – Port 2A, while the Interfering signal takes the path Port 1 – Port 2 – Port 1A – Port 2A. In this case, the unwanted signal undergoes two reflections (example, -40 dB each, giving total rejection of –80 dB). The two connectors are preferably part of a multi-way connector structure, as in Figure 17 or Figure 18. Alternatively, Port 2 could be connected internally to Port 1A, for example using an internal reflector.

A final embodiment of the optical connector in accordance with the invention is illustrated in Figure 24. In Figure 24 an optical connector in its second mode of use comprises first and second connector-portions 400, 402, in which are accommodated optical guides 404, 406, 408, 410 without theaddition of collimators or refractive elements. These guides converge at an angle (e.g. 45°) onto the respective mating surfaces, where again the mating surface of the first connector-portion 400 acts as a total internal reflector in the first mode of operation. Since the two connector-portions are in contact with each other, the

optical radiation in the optical guide 404 is passed straight through to the optical guide 408 and the return radiation entering the guide 410 is passed straight through to the guide 406.

In this embodiment, it is important that the mating ends of the optical guides be accurately cut and polished so as to avoid spurious airgaps, which might impair the transmission from the first connector-portion to the second and vice-versa.

It is possible to use the optical connector according to the invention in many different applications, and a few of these will now be described.

Figures 2b and 2c shows a basic use of a connector. An optical system is provided with one or more in-line first connector-portions of a connector. When it is desired to insert a new optical element into the line, the optical element is connected to the mating half, i.e. the second connector-portion, of the connector, as shown in Figures 2b and 2c. When the connector portions are mated, the optical signal is rerouted through the newly introduced optical element.

It is worth mentioning that, for certain functions, the new optical element need not be external to the second connector-portion, but could be integral with it. Examples would include filters, taps, sensors, isolators and/or optoelectronic components.

Figure 25 shows a conventional amplifier node incorporating a 2-channel optical add-drop multiplexer (OADM). Traffic from the West comprises a number of optical wavelengths. A filter arrangement selects and drops two of the wavelengths while passing the other wavelengths straight through. The filter arrangement also permits the addition of two wavelengths into the straight-through path. These filters could be tuneable or, more conventionally, are fixed due to the lower cost of fixed filters. If additional, or different wavelengths are required to be added or dropped, the straight through (or express) path would have to be broken to allow the addition of the new filters.

Figure 26 shows how this problem can be overcome using the optical connector of the present invention. A first connector-portion 170 is included into the line, as shown. An OADM filter 174 is connected to a second connector-portion in a loop configuration. When the two halves of the connector are mated, the signal is rerouted through the OADM filter. The interruption to the traffic is brief (<< 10 ms), which can be tolerated by many optical systems. In order to include further expansion capability, a second optical connector according to the invention 176 can be included in the loop.

Figure 27 shows a configuration in which it is desired to provide flexibility points between amplifier nodes. An example of this is a fibre routed around a city, where points need to be added to allow the capacity of the fibre to be tapped in the future. Here, first connector-portions 180, 182, 184, 186 according to the invention are included in-line, to allow the capacity to be re-routed through OADMs 188, 190 coupled to selected corresponding second connector-portions 192, 194, to allow wavelengths to be dropped or added to the line.

In a number of upgrade or maintenance scenarios, it is useful to be able to measure an optical signal on the line without breaking the traffic path. This can be accomplished by means of a connector coupled to a tap coupler 200 (which typically taps 1% to 10% of the signal), as shown in Figure 28. Again, the connector breaks the optical path for << 10 ms. The tapped signal can then be fed to measurement equipment 202 as required.

An alternative means of introducing an optical tap is by creating a small separation of order 1 micron between the two mating surfaces of the connector, which would cause partial frustration of the reflection at the interface and thereby allowing a fraction of the light in the first connector-portion to be coupled in to the respective guides of the second connector portion. One way in which this separation could be achieved is by appropriate design of the snap-action mechanism described earlier such that an intermediate closure force brings the two surfaces to a defined spacing.

In some scenarios, it is desirable to be able to add an amplifier to the line, in order to improve the performance. This may occur, for example, because capacity on the fibre has increased, or because the Optical Signal to Noise Ratio (OSNR) has degraded due to the addition of network elements such as OADMs, or due to degradation of the fibre plant – e.g, by accidental damage. In this case, an amplifier 204 can be inserted into the line using a connector according to the invention, as shown in Figure 29. If required, the line could first be measured using a temporary tap coupler as described above. The amplifier could then be pre-provisioned to the optimum operating parameters before being inserted into the line. In the case of an amplifier, and as already mentioned above, a second connector-portion configuration having high loss between ports in the unmated state may be desirable. This can be achieved with a configuration such as in Figure 21, with appropriate choice of parameters, or a configuration as shown in Figure 23.

Figure 30 shows a connector in accordance with the invention being used to enable the addition of a Raman amplifier into a system. The advantage of a Raman Amplifier over the more widely used Erbium Doped Fibre Amplifier is that the insertion loss in the un-powered state is low. This enables the Raman Amplifier to be added to the line with minimal interruption to traffic, and the amplifier gain slowly increased while maintaining a stable traffic path.

Figures31a and 31b show the use of a connector in accordance with the invention to link two existing rings – a main ring 206 and a secondary ring 208 - into a single larger ring. In practice, to achieve this the following steps are preferably taken: firstly, before the two connector-halves are mated, the traffic at those ring nodes adjacent the first connector-portion is rerouted; then the connector halves are mated and new paths are commissioned through the enlarged ring and, finally, the new paths are made available to the traffic which had been rerouted.

Dispersion is an important problem in many optical systems, since it causes pulse spreading as the signal travels along fibre systems. Dispersion is a particular issue on higher speed systems (10 Gbps and upwards) or with non-

optimum fibre types. A simple optical-fibre system (e.g. 2.5 Gbps, few wavelengths) can be deployed with minimal dispersion compensation. Upgrade of some wavelengths to 10 Gbps/40 Gbps then requires the addition of Dispersion Compensating Modules (DCMs) or Dispersion Slope Compensating Modules (DSCMs). This can be accomplished by first measuring the signal quality using an optical connector according to the invention with tap coupler and dispersion measurement equipment, as partially described in connection with Figure 28. The dispersion measurement equipment can then be used to calculate the optimum value of a fixed dispersion compensation. This tap coupler and measurement equipment can then be replaced by a low-cost fixed DCM or DSCM, as shown in Figure 32.

Figure 33 shows a number of connectors 220a, 220b in accordance with the invention being used in an optical backplane application. The configuration allows circuit boards 222 to be plugged into the backplane 224, with the optical signal being routed through each such board to an optical element or module 226 mounted on the board. The backplane connectors may be single connectors or "multiple" connectors, as shown in Figures 17 and 18. Various configurations of "wiring up" the backplane are of course possible, only one being shown here. It is advantageous in this application to use connectors which permit the signal to be rotated through large angles, for example as shown in Fig 14. A mix of connector types is of course possible, e.g. a connector-portion configuration as shown in Figure 2 on the backplane together with a mating connector-portion configuration as shown in Figure 4. This requires that the optical radiations (beams) in the optical guides subtend the same angles in the two configurations (e.g. 45° to the normal) and that the beam diameters and index of the mating surfaces also match between the two. The external interface to the backplane (if required) may be directly via an off-shelf connector 228, or could be via on-card connectors (not shown).

Many other applications for the inventive optical connector can be envisaged, one such (not illustrated) being the ad-hoc addition of power taps in a broadcast system (e.g. a CATV (cable-access television) system).

A further aspect of the invention will now be described.

An important issue in optical systems is eye safety. An unconnected standard optical connector (e.g. FC/PC type) has the potential to emit levels of optical radiation hazardous to the eye. Optical systems employing high levels of optical power (e.g. amplified systems) can suffer these problems, and are required to have Automatic Line Shutoff (ALS) features to limit exposure to radiation. These systems typically use an optical signal reflected from a fibre break or unmated connector to trigger the ALS.

The first connector-portion of an optical connector according to the invention will not emit significant levels of radiation when employed in its first mode of use, provided the second optical guide is properly terminated. Where the optical connector is only required to be of the single-port type, it is possible to terminate the second port (second optical guide) internally within the connector. Figure 34a shows the first connector-portion of the afore-described first embodiment of an optical connector according to the invention, in which a fibre 300 is accommodated in the body 302 of the connector portion and communicates with a collimating element 304, which in turn is connected to a prism 306 acting at its outwardly facing side 310 as a total internal reflecting surface. A protective cover 308 may optionally also be provided as explained earlier in connection with this embodiment.

Different here, however, is the fact that the optical signal reflected from the surface 310 is absorbed in an optical dump 312 provided on the face 313 of the prism 306 upon which the reflected signal impinges. As an alternative, a reflector may be provided at this point, which will reflect the impinging signal back along substantially the same path, this return signal then being again reflected from the face 310 and back along the optical fibre 300 in the opposite direction. This will have the effect of enhancing the return signal which is relied on in the earlier described ALS systems. (In such known systems the main reflecting surface (here 310) is usually normal to the fibre axis). If it is desired to maintain the same reflectivity as a standard FC/PC type optical connector, the reflector could be in the form of an air gap.

The more normal mode of operation of such an eye-safe arrangement is to have the first connector-portion illustrated in Figure 34a connected to its corresponding second connector-portion (see Figure 34b). The latter would take the form of the second connector-portion shown in Figure 2b, . As with the first connector-portion shown in Figure 34a, this second connector-portion would have a single optical port (optical guide) for passing the optical signal on to the fibre section to which the second connector-portion was connected.

As a still further alternative, a fluorescent material may be used as the coating 312, this then providing a visual indication of the presence of an optical signal within the connector to service personnel, who can then take any required action.

A variant of the latter arrangement is illustrated in Figure 35. In Figure 35 the afore-mentioned coating 312 is replaced by a string of three or four photodiodes in series with a visible LED or laser 314, which will again provide a visual indication of a fibre break.

In practice, with any of these variants, the second connector-portion could be identical to the first connector-portion, i.e. it could include its own optical dump/reflector,etc 312. The latter, however, would fulfil no function in the second connector-portion.

Also, instead of using the angled optical-guide configuration of the first embodiment (Figure 2), any of the other configurations may also be employed (e.g. Figure 4).

A second embodiment of an eye-safe connector arrangement is the subject of Figures 36a and 36b, in which a fibre is shown terminated in a connector-portion 320. The end of the fibre, which is received in a receiving means 321 is inserted in a ferrule 322, the outer end of which is angled, as shown. The cut, an enlarged version of which is shown as item 324 in Figure 36b, is made so that the optical signal impinging on the angled end-face of the ferrule is

reflected towards the side-wall of the ferrule, as shown by the arrow, where it is absorbed.

In the other mode of use of the illustrated connector, a similar connector-portion is offered up to the end of the ferrule of the connector-portion 320 shown, so that the total internal reflecting operation at the ferrule/air interface 324 is frustrated, the signal then being able to pass into the opposing ferrule 325 and out into its own associated fibre section

The advantages of the present optical connector can be summarised as follows:

(1) It allows the upgrading of an existing system with absolutely minimal disruption to traffic.

(2) It simplifies network planning by allowing later upgrades with OADM filters, etc, again with minimal impact on existing traffic.

(3) It reduces CAPEX (capital expenditure) by enabling a pay-as-you-grow policy to be followed (e.g. can add OADM filters as and when needed).

(4) It decreases OPEX (operational expenditure) by simplifying the upgrading process, and

(5) It improves network performance by eliminating unnecessary components and by allowing in-service upgrades with amplifiers and DSCMs, etc.

CLAIMS

1. An optical connector having first and second connector-portions, the first connector-portion comprising first and second optical guides for respectively receiving and transmitting first and second optical radiations, and a first, total internal reflection surface upon which, in use, the first optical radiation impinges; the second connector-portion comprising a second surface for placing against said first surface thereby to frustrate the total internal reflection function of said first surface, the second connector-portion being associated in use with an optical element;
the optical connector being adapted for two modes of use:
- a first mode, which excludes the second connector-portion and in which the first connector-portion is inserted in a first optical-fibre arrangement having a given functionality and the first surface reflects the first optical radiation into the second optical guide, and
- a second mode, in which the connector-portions are mated together such that the second surface is held firmly against the first surface and accurately aligned therewith, thereby frustrating said total internal reflection and allowing the optical radiation from the first optical guide to pass through to the second connector-portion and interact with the optical element, whereby the functionality of the optical-fibre arrangement is increased.

2. Optical connector as claimed in Claim 1, wherein the second connector-portion comprises third and fourth optical guides having respective first and second ends, the first ends being orientated towards the second surface and the second ends being connected, in use, to said optical element.

3. Optical connector as claimed in Claim 2, wherein the second connector-portion has a refractive-index matching means applied to the second surface for minimising reflections at the interface of the mated first and second surfaces.

4. Optical connector as claimed in Claim 3, wherein the first connector-portion during said first mode of use comprises a protective cover for protecting the first surface from contamination.

5 Optical connector as claimed in any one of Claims 2-4 wherein first and second connector portions are aligned in a mechanism which provides a snap-action final closure from a pre-set distance.

6. Optical connector as claimed in any one of Claims 2 to 5, wherein the first and second optical guides are substantially parallel.

7. Optical connector as claimed in any one of Claims 2 to 5, wherein the first and second optical guides are normal to the first surface.

8. Optical connector as claimed in any one of Claims 2 to 7, comprising a refractive element between the first and second optical guides and the first surface and the third and fourth optical guides and the second surface.

9. Optical connector as claimed in Claim 8, wherein the refractive element comprises a graded-index lens.

10. Optical connector as claimed in Claim 8, wherein the refractive element comprises a high refractive-index ball lens.

11. Optical connector as claimed in Claim 7, comprising an optical element between the first and second optical guides and the first surface and the third and fourth optical guides and the second surface, the optical element of the first connector-portion comprising first and second reflecting

surfaces for reflecting the normally orientated optical radiation in the first and second optical guides respectively onto and from said first surface.

12. Optical connector as claimed in Claim 11, wherein said first and second reflecting surfaces comprise a reflector attached to said optical element.

13. Optical connector as claimed in Claim 11, wherein said first and second reflecting surfaces comprise a low refractive-index medium adjoining said optical element.

14. Optical connector as claimed in Claim 13, wherein the low refractive-index medium is one of: an airgap, a glass material and a vacuum.

15. Optical connector as claimed in Claim 11, wherein said first and second reflecting surfaces are part of a continuous surface of a lens element.

16. Optical connector as claimed in Claim 11, wherein the optical element of each of the connector-portions comprises a prism having two outer faces, the optical radiation in the first optical guide in the first mode of use being reflected into the second optical guide.

17. Optical connector as claimed in Claim 16, wherein, in said second mode of use, one of the outer faces of the prism of the first connector-portion adjoins one of the faces of the prism of the second connector-portion.

18. Optical connector as claimed in Claim 17, wherein the first and second optical guides form an angle of approximately 90° with the third and fourth optical guides.

19. Optical connector as claimed in Claim 18, comprising a third connector-portion similar to the second connector-portion and having fifth and sixth optical guides, the fifth and sixth optical guides forming an angle of approximately 90° with the first and second optical guides of the second connector-portion and wherein radiation from the first optical guide passes

into the fourth optical guide, radiation from the third optical guide passes into the sixth optical guide and radiation from the fifth optical guide passes into the second optical guide.

20. Optical connector as claimed in Claim 2, wherein the first and second connector-portions have attached to them respective optically transmissive blocks adjacent the first and second surfaces, respectively, the blocks being attached in hermetically sealed or moisture-sealed manner by way of a flexible membrane, wherein in said second mode of use said blocks are held firmly against each other and against their associated respective first and second surfaces so as to minimise reflections.

21. Optical connector as claimed in Claim 2, wherein the first connector-portion has attached to it an optically transmissive membrane adjacent the first surface, the membrane being spaced from the first surface in the first mode of use and attached in hermetically sealed or moisture-sealed manner, wherein in the second mode of use the membrane is held firmly against the respective first and second surfaces so as to minimise reflections

22 Optical connector as claimed in claim 20 or 21 wherein the position of the third and fourth optical guides and the thickness of the blocks or membrane are adapted for low loss in the mated state while achieving high isolation between the third and fourth optical guides in the unmated state of the second connector-portion.

23. Optical connector as claimed in any one of the preceding claims, wherein the second connector-portion is substantially identical to the first connector-portion.

24. Optical connector arrangement comprising an optical connector as claimed in Claim 1, each first connector-portion comprising a plurality of pairs of first and second optical guides.

25. Optical connector arrangement as claimed in Claim 24, further comprising a central optical guide, the pairs of optical guides being disposed around said central optical guide.

26. Optical connector arrangement as claimed in Claim 25, wherein the pairs of optical guides are disposed in hexagonal fashion around the central optical guide.

27. Optical connector arrangement comprising an array of optical connectors as claimed in Claim 1.

28. Optical connector arrangement as claimed in Claim 27, wherein the first optical guides and the second optical guides of each of the optical connectors are mounted on respective first and second support members.

29. An optical-fibre network comprising an optical connector arrangement as claimed in Claim 25 or Claim 26, wherein the central optical guide can be used for network-monitoring purposes or as an optical service channel.

30. An optical connector having first and second connector-portions,
the first connector-portion comprising a first optical guide for carrying optical radiations from a first optical fibre, a first, total internal reflection surface upon which, in use, said radiations impinge, and a means for enhancing an eye-safe operation of the optical connector; the second connector-portion comprising a second optical guide for carrying optical radiations to a second optical fibre and a second surface for placing against the first surface thereby to frustrate the total internal reflection function of said first surface;
the optical connector being adapted for two modes of use:
- a first mode, in which the first and second connector-portions are mated together such that the second surface is held firmly against the first surface and accurately aligned therewith, thereby frustrating said total internal reflection and allowing the optical radiations from the first optical guide to pass through to the second optical guide, and

- a second mode, in which the first and second connector-portions are separated, so that the radiations in the first optical guide are reflected by the first surface into the means for enhancing an eye-safe operation, whereby the eye-safe operation of the first connector-portion can be enhanced.

31. An optical network section into which is connected the first connector-portion of one or more optical connectors as claimed in any one of Claims 1 to 22.

32. Optical network section as claimed in Claim 31, wherein at least one of the second connector-portions of the one or more optical connectors is connected in turn to one or more add-drop multiplexers.

33. Optical network section as claimed in Claim 31, wherein at least one of the second connector-portions of the one or more optical connectors is connected in turn to a first connector-portion of a further optical connector as claimed in any one of Claims 1 to 19.

34. Optical network section as claimed in any one of Claims 31 to 33, wherein at least one of the second connector-portions is connected to an optical amplifier.

35. Optical network section as claimed in any one of Claims 31 to 34, wherein at least one of the second connector-portions of the one or more optical connectors is connected in turn to a network ring.

36. Optical network section as claimed in any one of Claims 31 to 35, wherein at least one of the second connector-portions of the one or more optical connectors is connected in turn to a Raman pump in order to increase optical gain.

37. Optical network section as claimed in any one of Claims 31 to 36, wherein at least one of the second connector-portions of the one or more optical

connectors is connected in turn to diagnostic apparatus in order to be able to diagnose the behaviour of the network section.

38. Optical network section as claimed in any one of Claims 31 to 37, wherein at least one of the second connector-portions of the one or more optical connectors is connected in turn to a power tap as part of a broadcast system.

39. A method of increasing the functionality of an optical network by the addition of an optical element, comprising:
(a) equipping the network with the first connector-portion of an optical connector as claimed in any one of Claims 1 to 18;
(b) connecting the optical element to the second connector-portion of the optical connector, and
(c) mating together the first and second connector-portions.

40. Method as claimed in Claim 39, wherein the optical network is a primary ring having a plurality of network nodes and the optical element is a secondary network ring, whereby the primary ring is enlarged by the addition of the secondary ring.

41. Method as claimed in Claim 40, including the further steps of:
(b') prior to step (c), rerouting traffic at nodes adjacent the first connector-portion;
(d) following step (c), commissioning new paths through the enlarged ring, and
(e) switching to said new paths.

42. Method of upgrading dispersion control in a network, comprising:
(a) equipping the network with the first connector-portion of an optical connector as claimed in Claim 1;
(b) equipping the second connector-portion of the optical connector with a tap coupler;

(c) connecting dispersion-measurement apparatus to the tap coupler to determine the value of dispersion slope compensation required;

(d) removing the tap coupler from the second connector-portion, and

(e) connecting to the second connector-portion a dispersion slope compensation module (DSCM) having the determined compensation value.

43. An optical connector device for mating with a corresponding optical connector device having a total-internal-reflection frustrating mating surface and associated, in use, with an optical element, the optical connector device comprising first and second optical guides for respectively receiving and transmitting first and second optical radiations, and a total internal reflection surface upon which, in use, the first optical radiation impinges and against which the mating surface of the corresponding optical connector device can be firmly held.

44. Optical connector device as claimed in Claim 43, wherein the corresponding optical connector device is substantially identical to the optical connector device.

45. An optical connector substantially as shown in, or as hereinbefore described with reference to, any of: Figures 2a, 2b and 2c, Figures 4 and 5, Figures 6a, 6b and 6c, Figure 7, Figure 8, Figure 9, Figures 10a and 10b, Figure 11, Figure 12, Figure 13, Figure 14, Figure 15, Figure 16, Figures 19 and 20, Figure 21a, Figure 21b, Figure 22 and Figure 24.

46. An optical connector arrangement substantially as shown in, or as hereinbefore described with reference to, any of: Figure 17, Figure 18, Figure 23 and Figure 33.

47. An optical connector substantially as shown in, or as hereinbefore described with reference to, Figures 34a and 34b, Figure 35 or Figures 36a and 36b.

ABSTRACT

OPTICAL CONNECTOR

In an optical connector for fibre-optic use a first portion of the connector is inserted in an existing fibre section with a view to later upgrading the section as appropriate with one or more optical elements, e.g. OADM's, amplifiers and the like. When the need for an upgrade arises, a second portion of the connector is connected to the item which is required to be inserted into the existing section and the two portions of the connector then mated together. In the mating process, a total internal reflecting surface of the first connector-portion, which in the existing fibre system simply reflects an optical signal back into the system, now passes the optical signal on into the second connector-portion and into the added optical element, thereby bringing that element into operation in the existing network with minimal disruption to network traffic.

Figure 2c

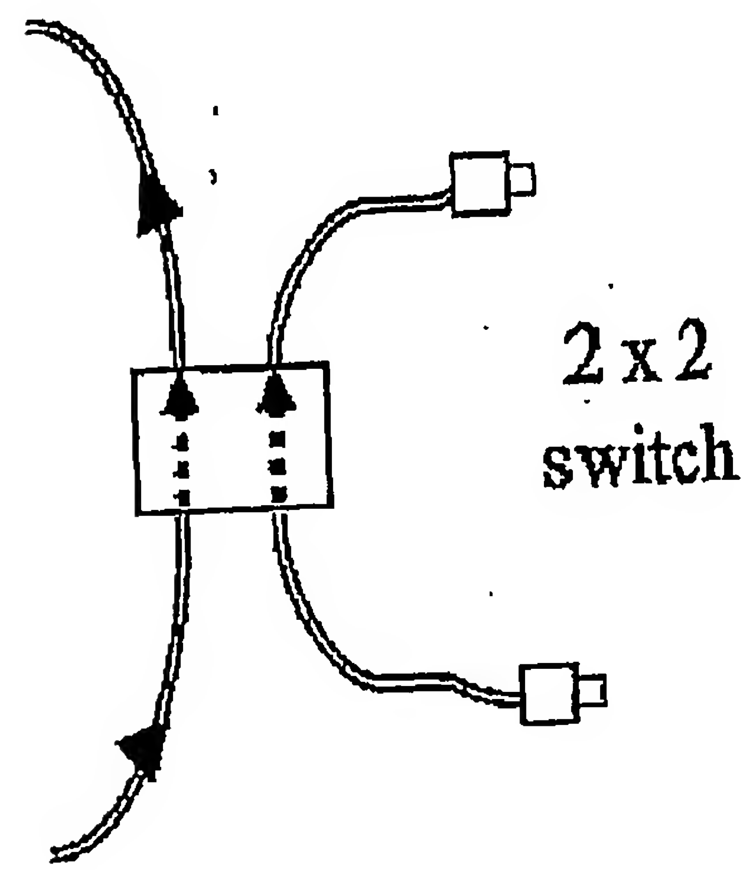
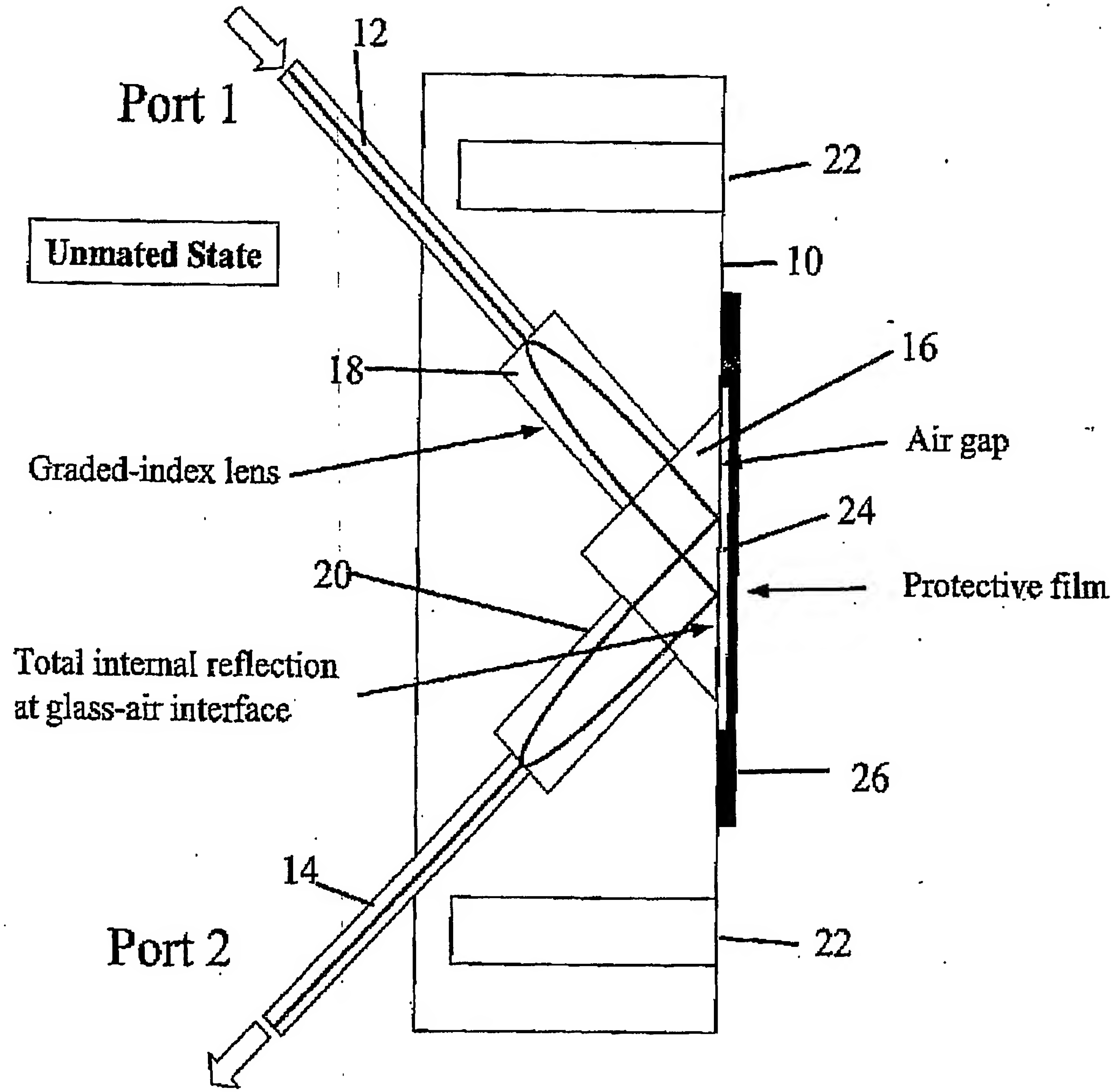
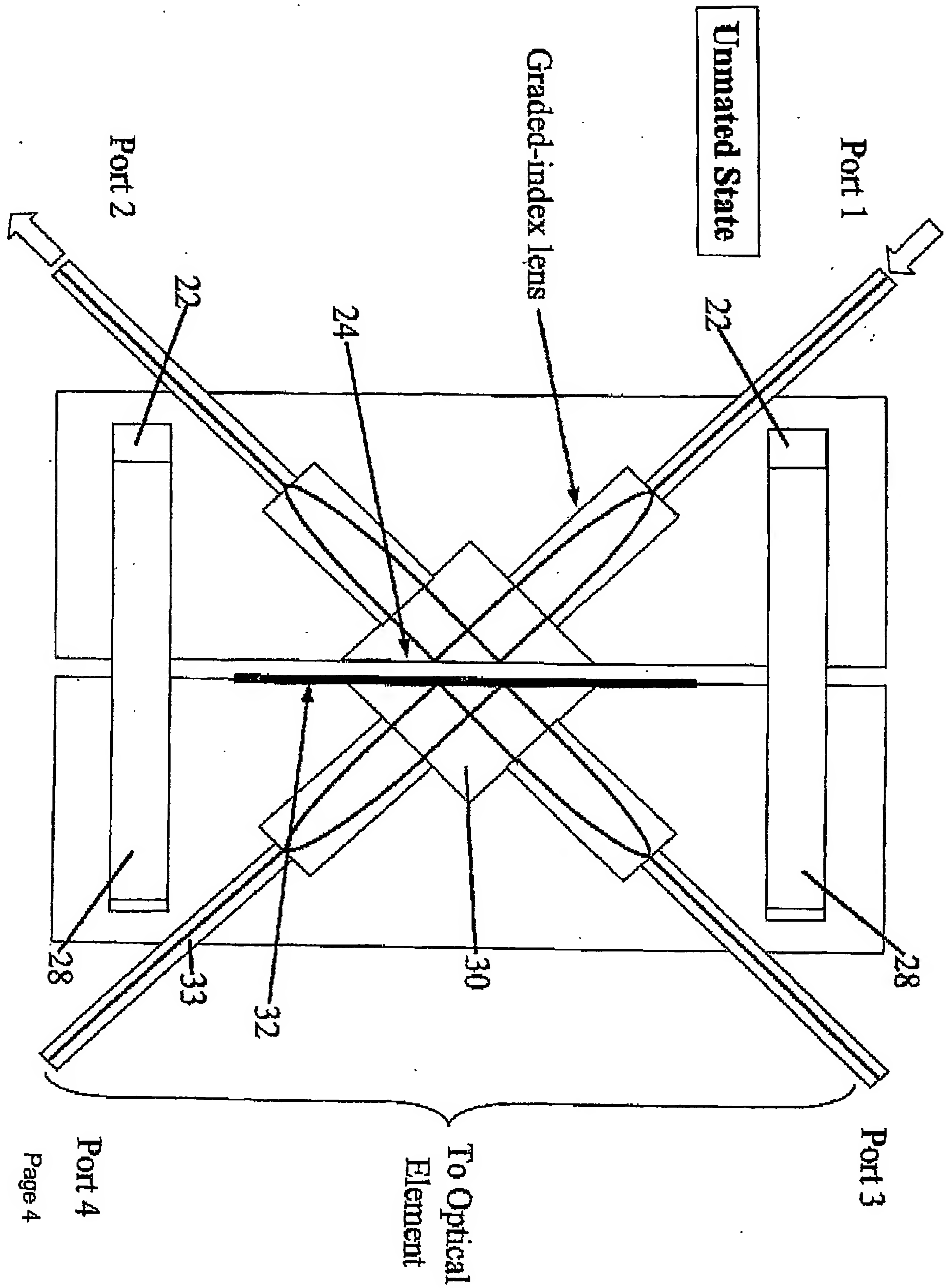


FIG. 1

FIG. 2a


Port 1
12
22
Unmated State
10
16
18
Graded-index lens
Air gap
24
20
Protective film
Total internal reflection
at glass-air interface
26
14
22
Port 2



Unmated State
Port 1
Graded-index lens
Port 2
22
24
22
28
33
32
30
28
Port 3
To Optical
Element
Port 4

FIG. 2b

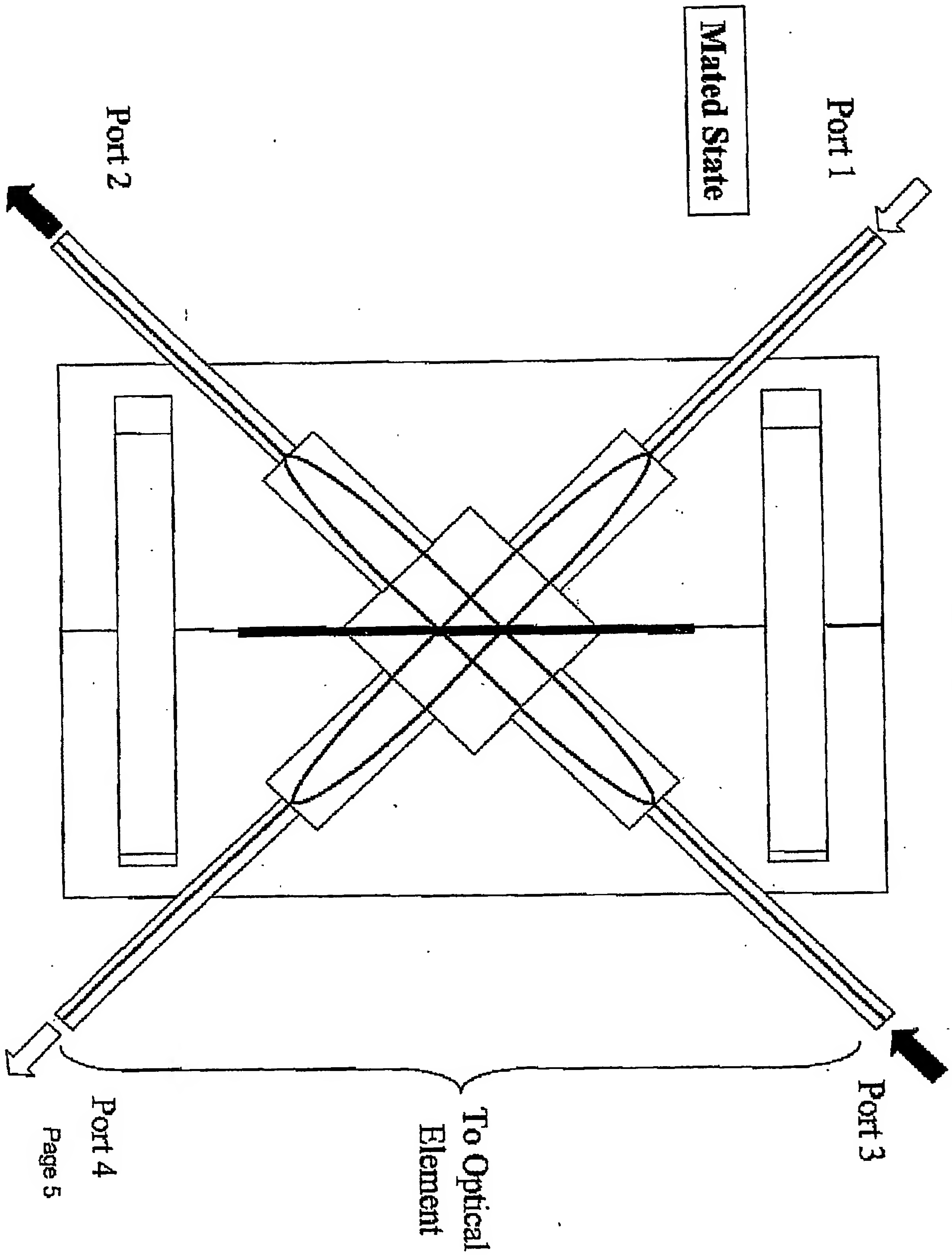
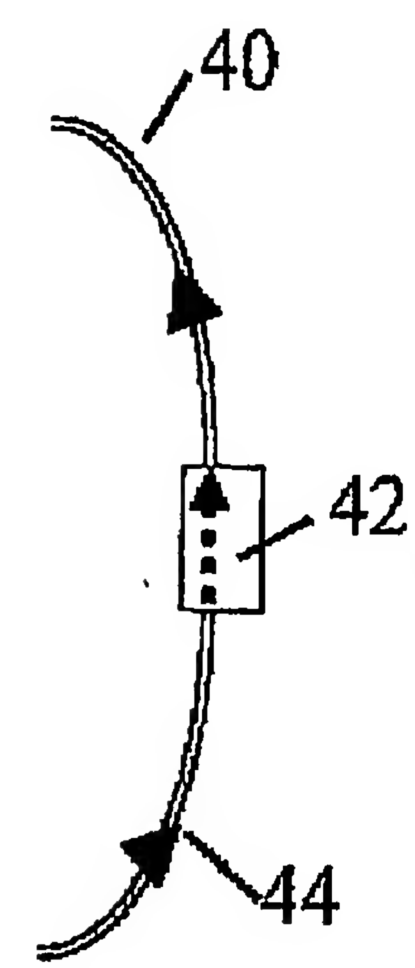
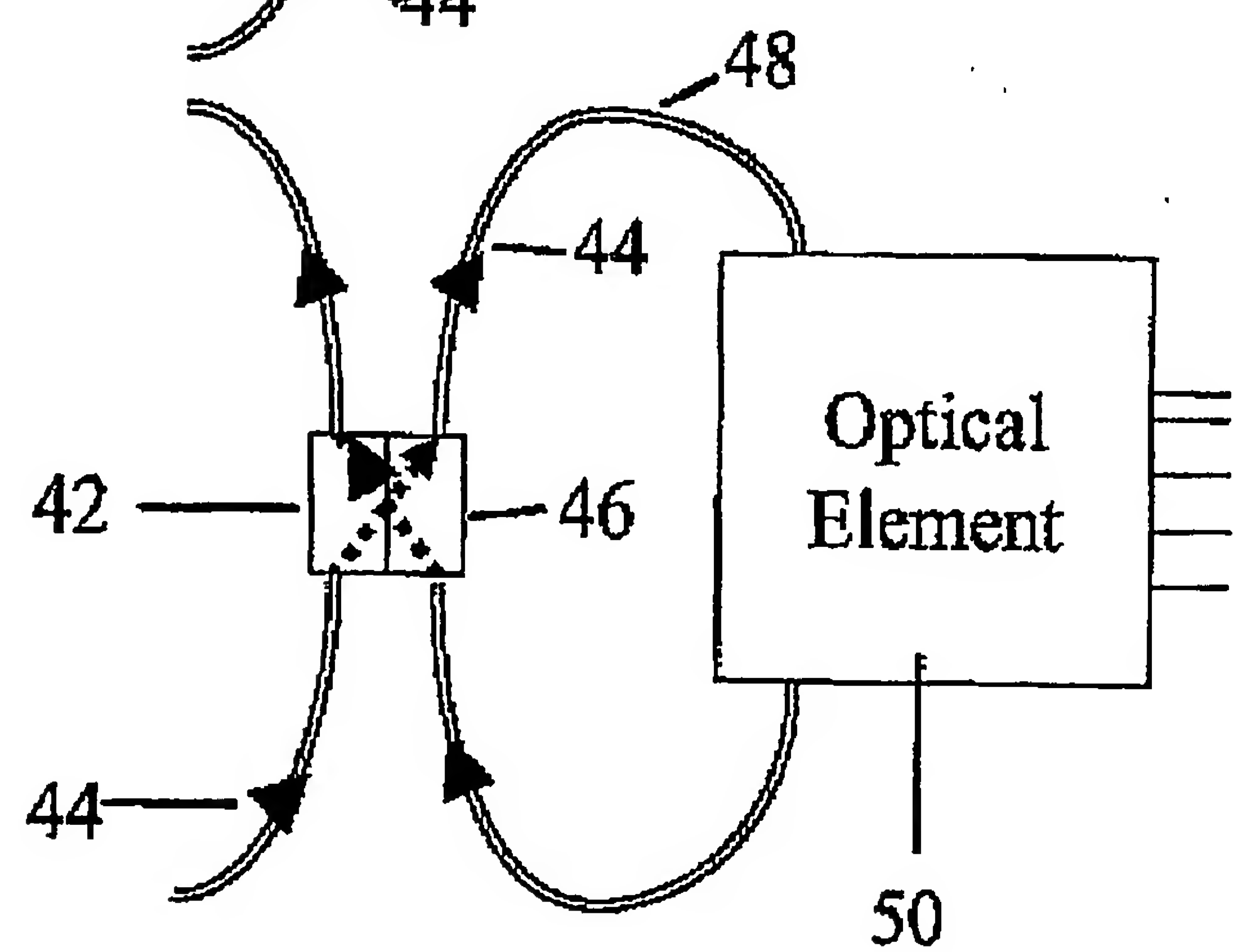


FIG. 2c

FIG. 3



- Can distribute a number of low loss, passive Optical Connectors in a line system
- Place at any point where a future upgrade *may* be required



- When mating half of Optical Connector is plugged in, all express traffic is immediately rerouted through optical element and back onto line
- Optical element could be OADM filter for example

FIG. 4

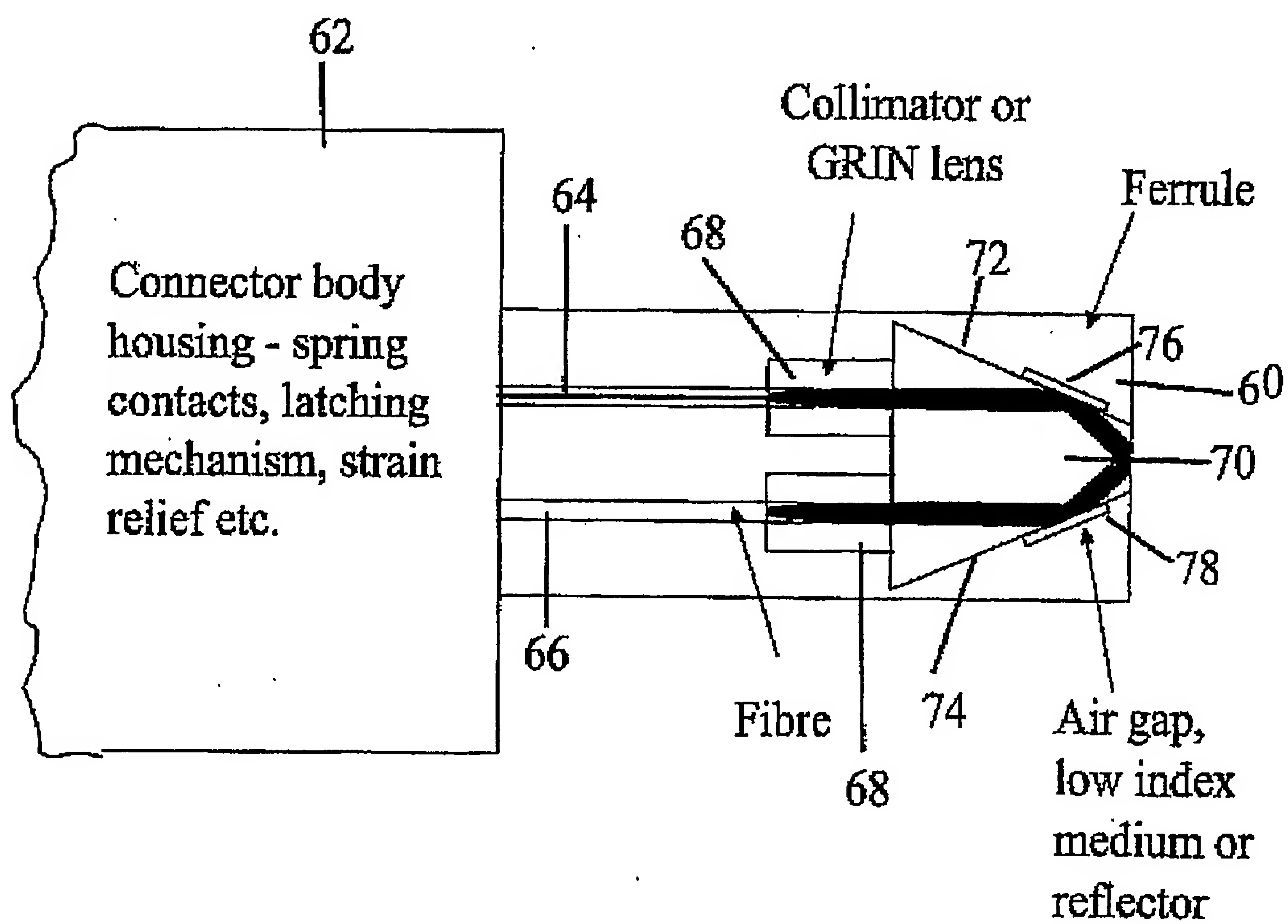

62
Connector body housing - spring contacts, latching mechanism, strain relief etc.
64
68
Collimator or GRIN lens
72
Ferrule
76
60
70
78
66
Fibre
68
74
Air gap, low index medium or reflector

Fig 5

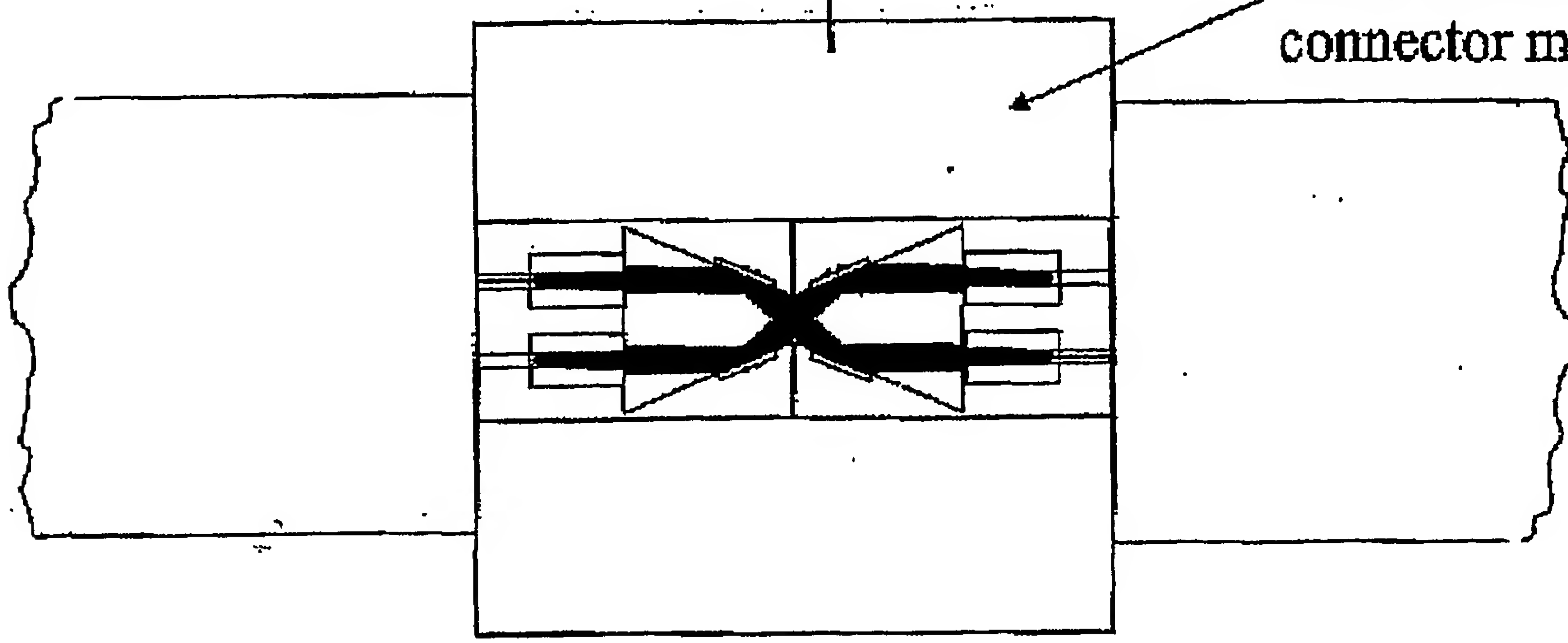


FIG. 6a

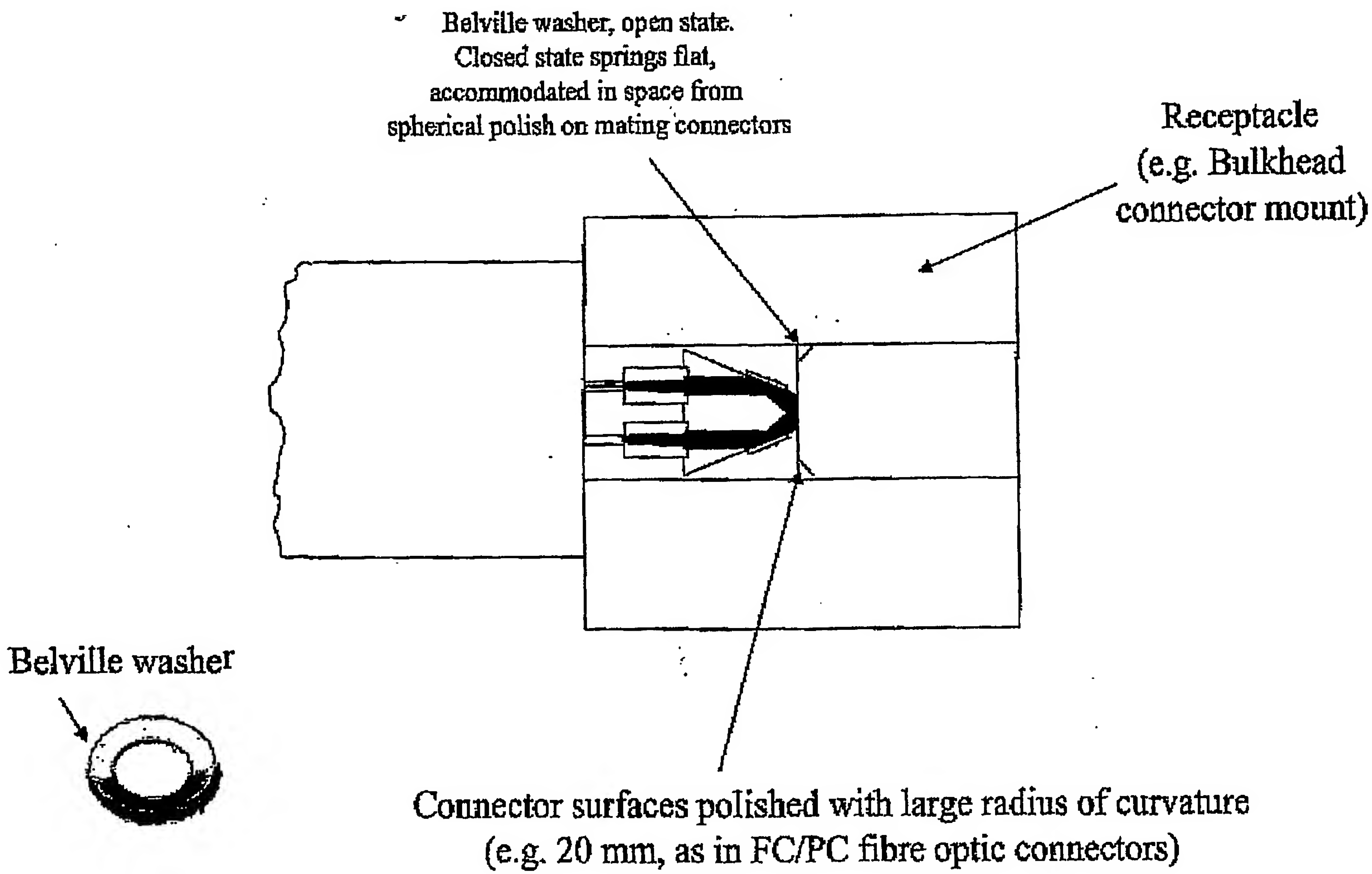
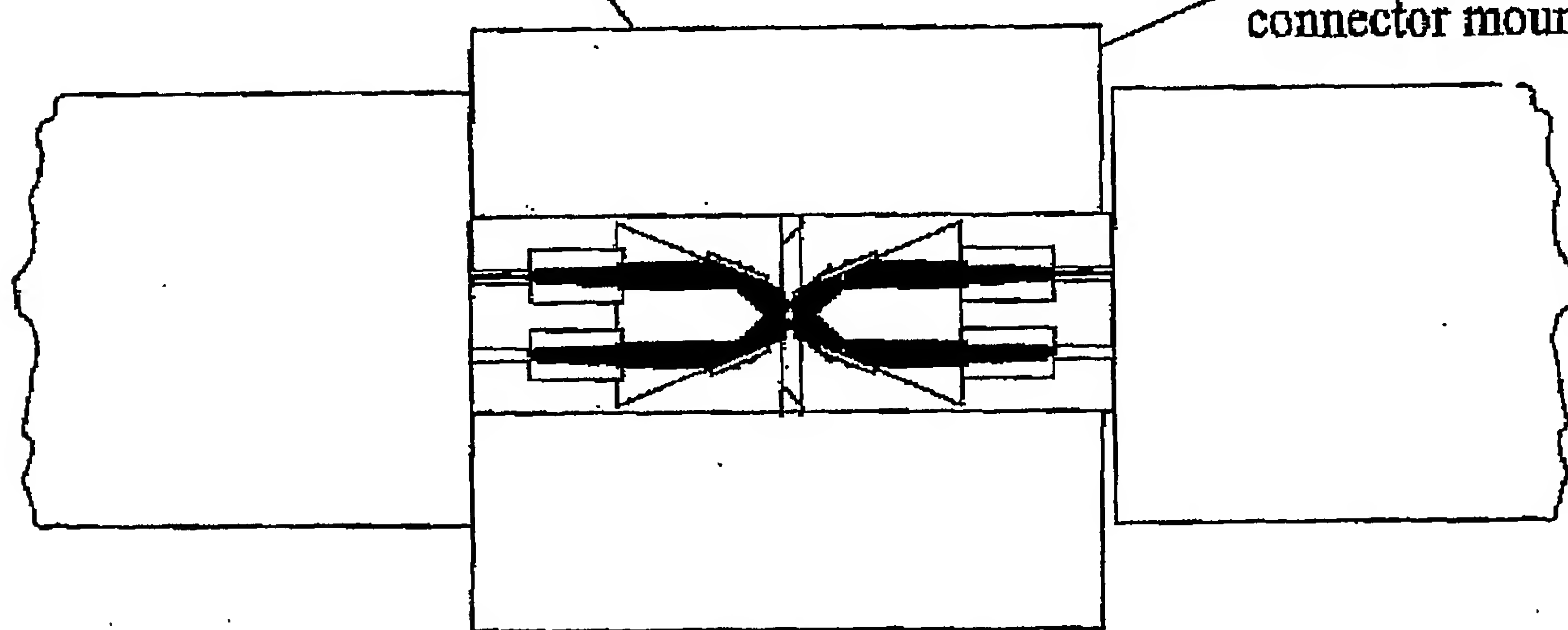

Belville washer, open state.
Closed state springs flat,
accommodated in space from
spherical polish on mating connectors
Receptacle
(e.g. Bulkhead
connector mount)
Belville washer
Connector surfaces polished with large radius of curvature
(e.g. 20 mm, as in FC/PC fibre optic connectors)

FIG. 6b


Belville washer, open state.
Closed state springs flat,
accommodated in space from
spherical polish on mating connectors
Receptacle
(e.g. Bulkhead
connector mount)
Connector surfaces polished with large radius of curvature
(e.g. 20 mm, as in FC/PC fibre optic connectors)

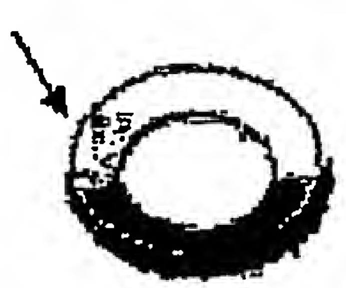

Belville washer

FIG 6c

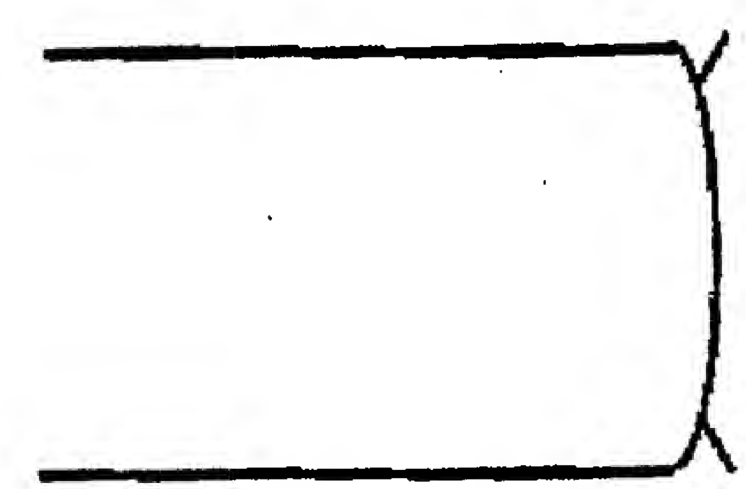


FIG. 7

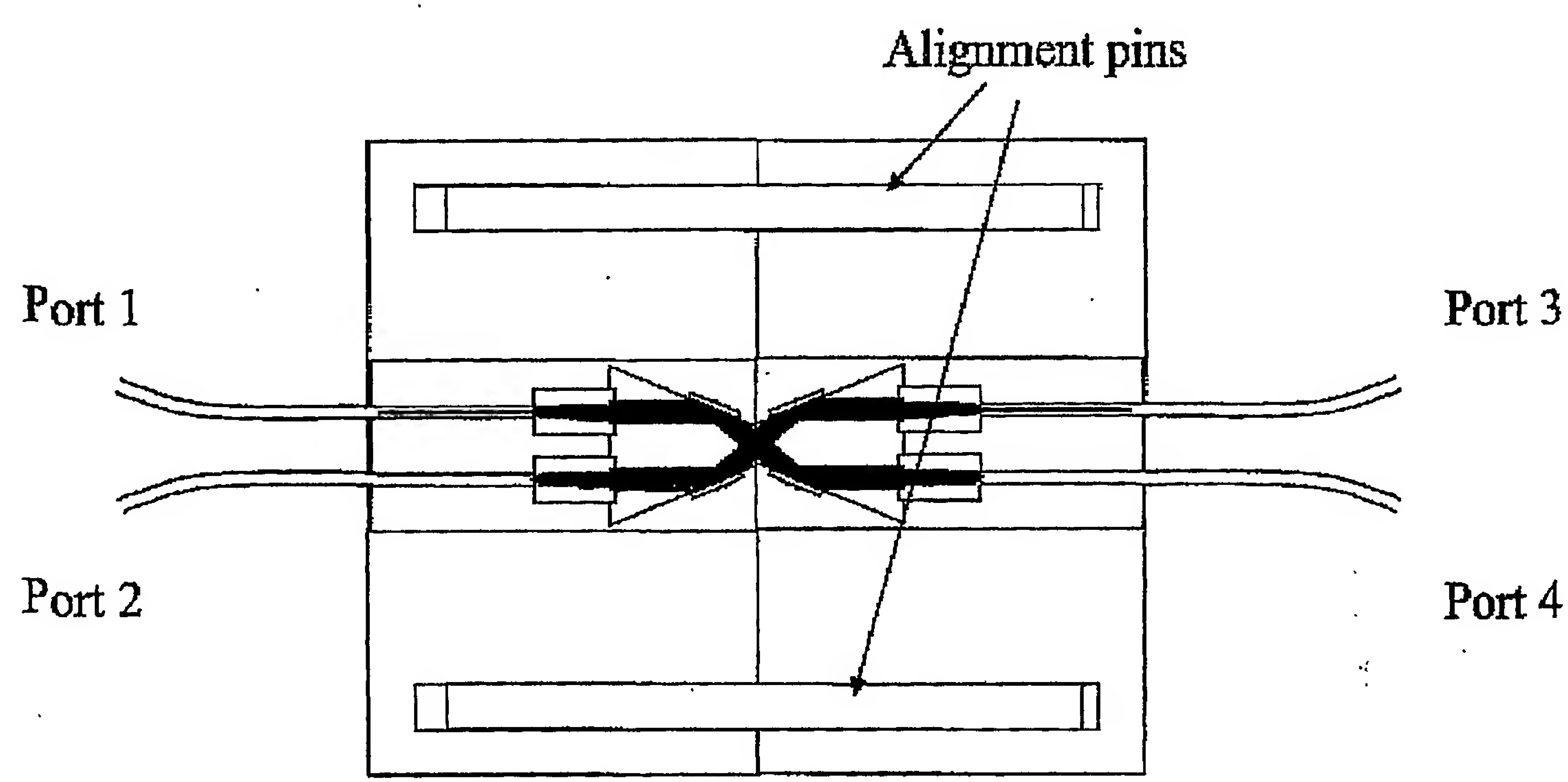
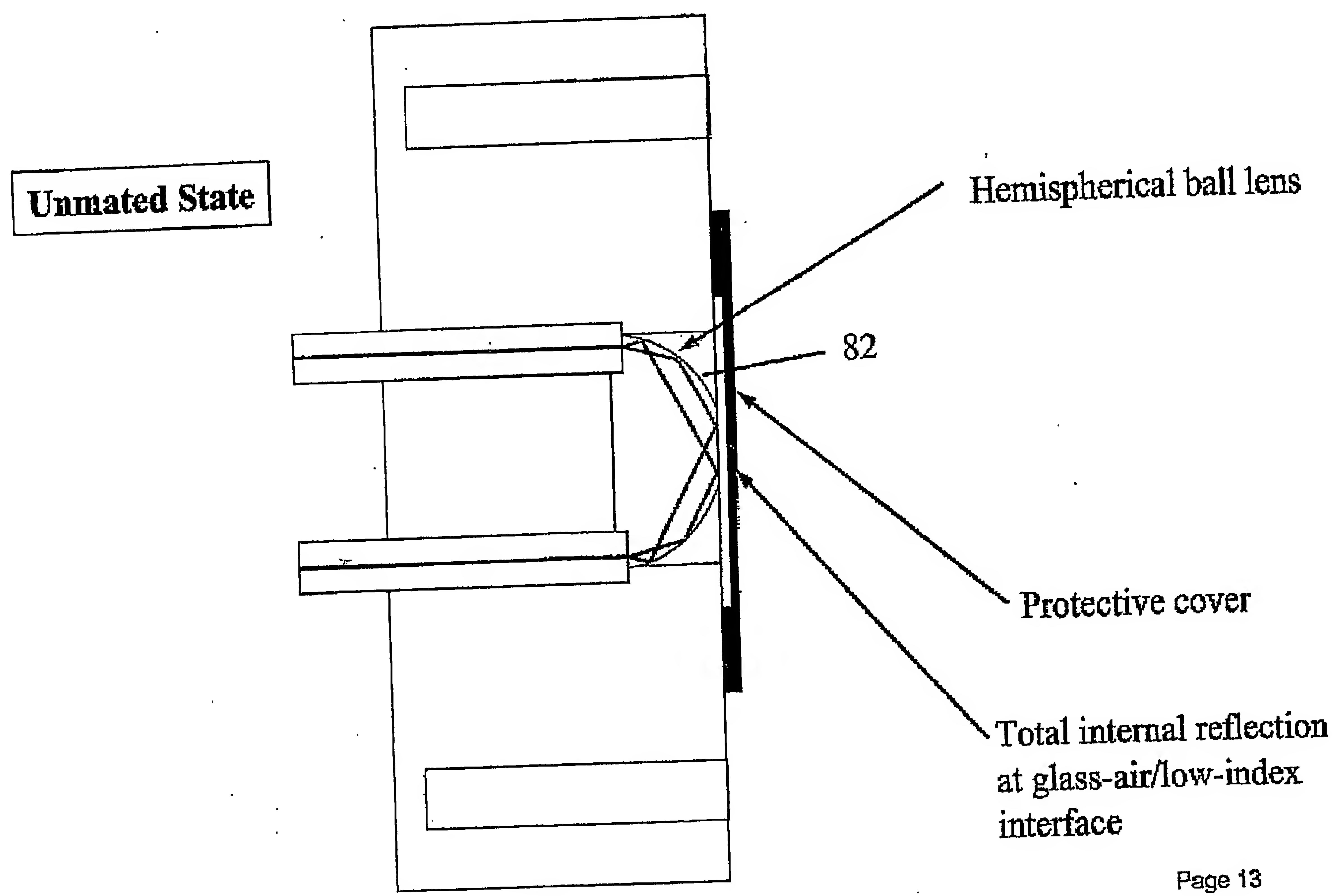


FIG. 8



Unmated State
Hemispherical ball lens
82
Protective cover
Total internal reflection at glass-air/low-index interface

FIG. 9

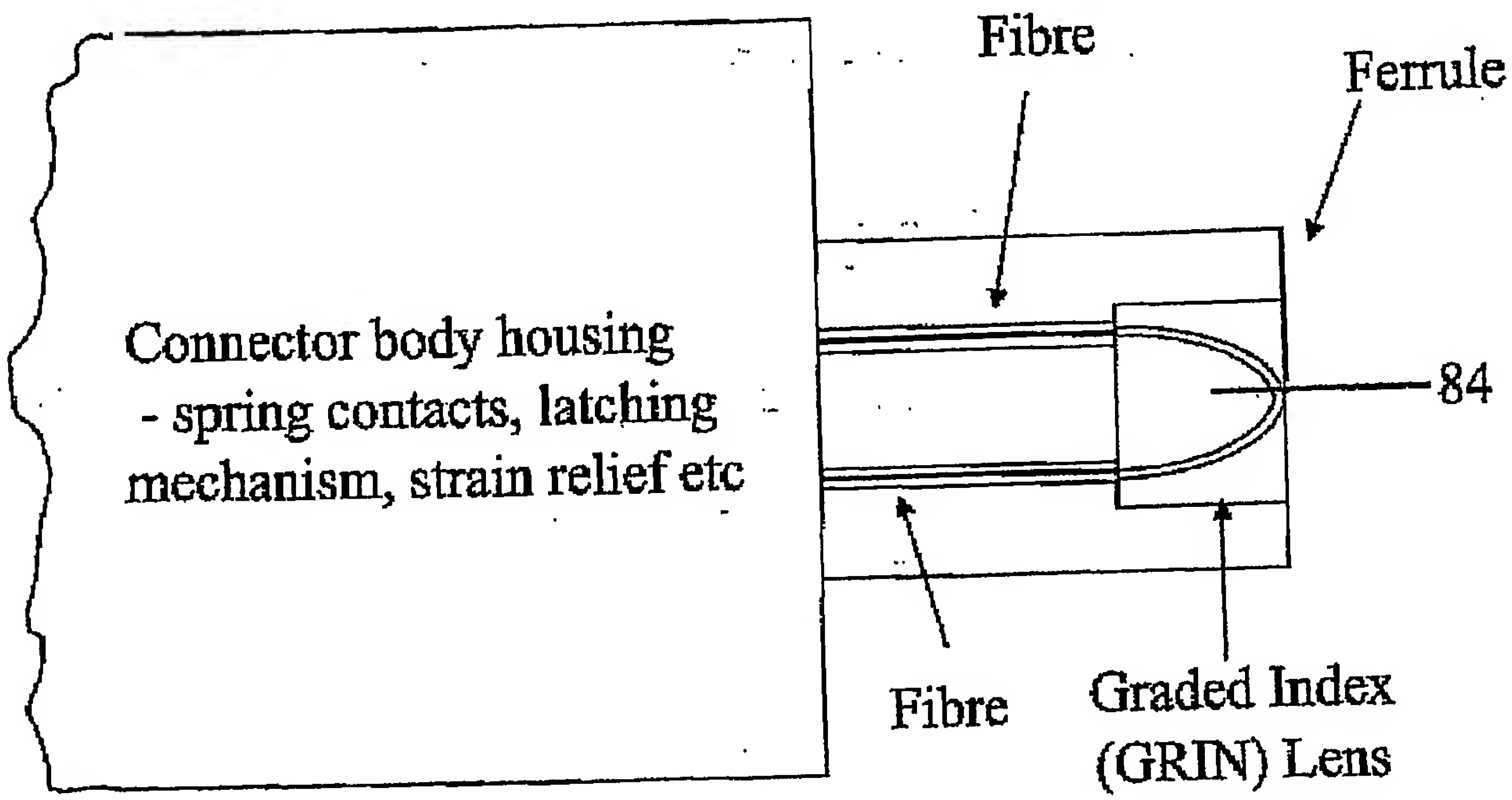

Connector body housing
- spring contacts, latching
mechanism, strain relief etc
Fibre
Ferrule
84
Fibre
Graded Index
(GRIN) Lens

FIG. 10a

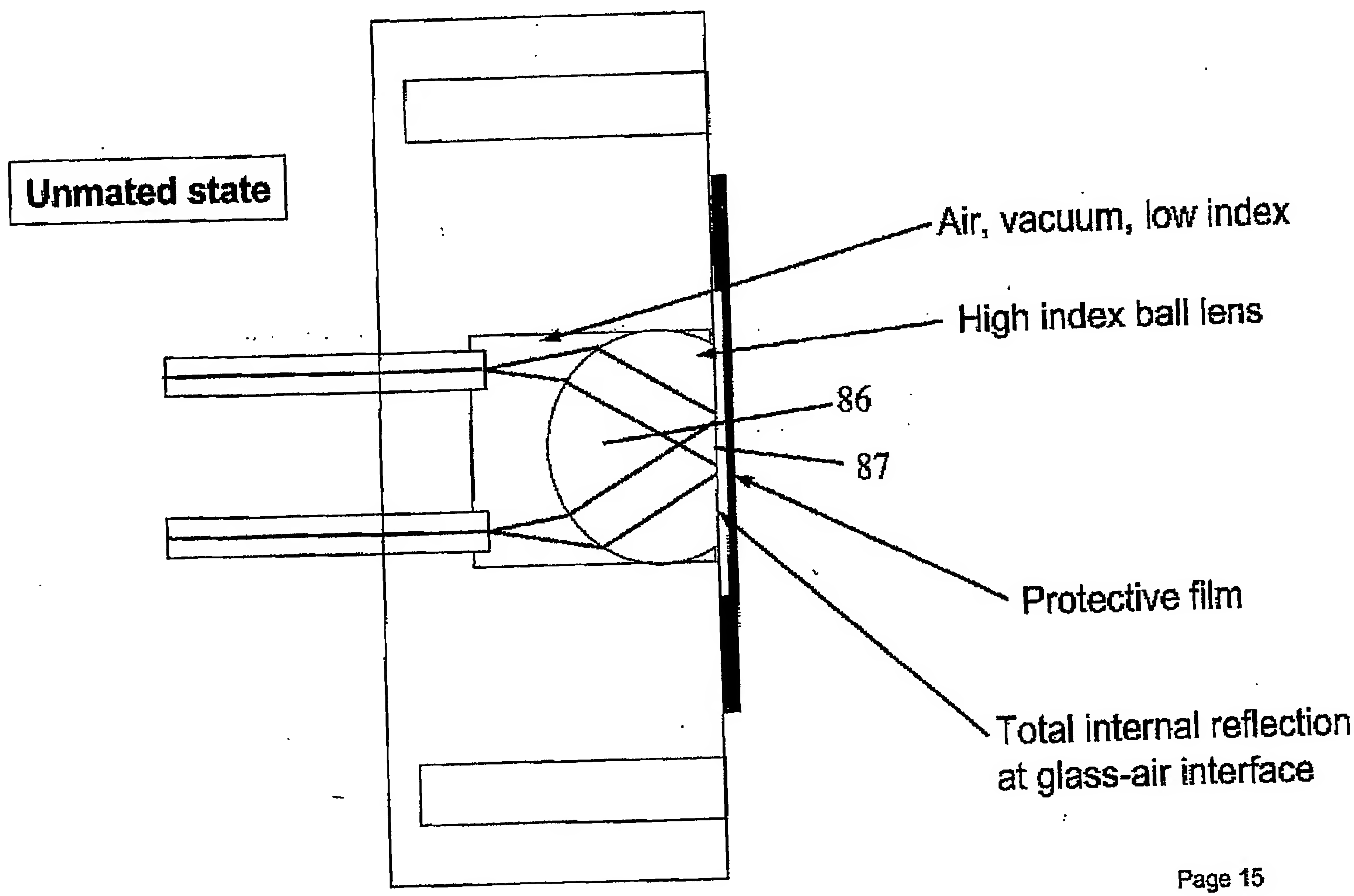
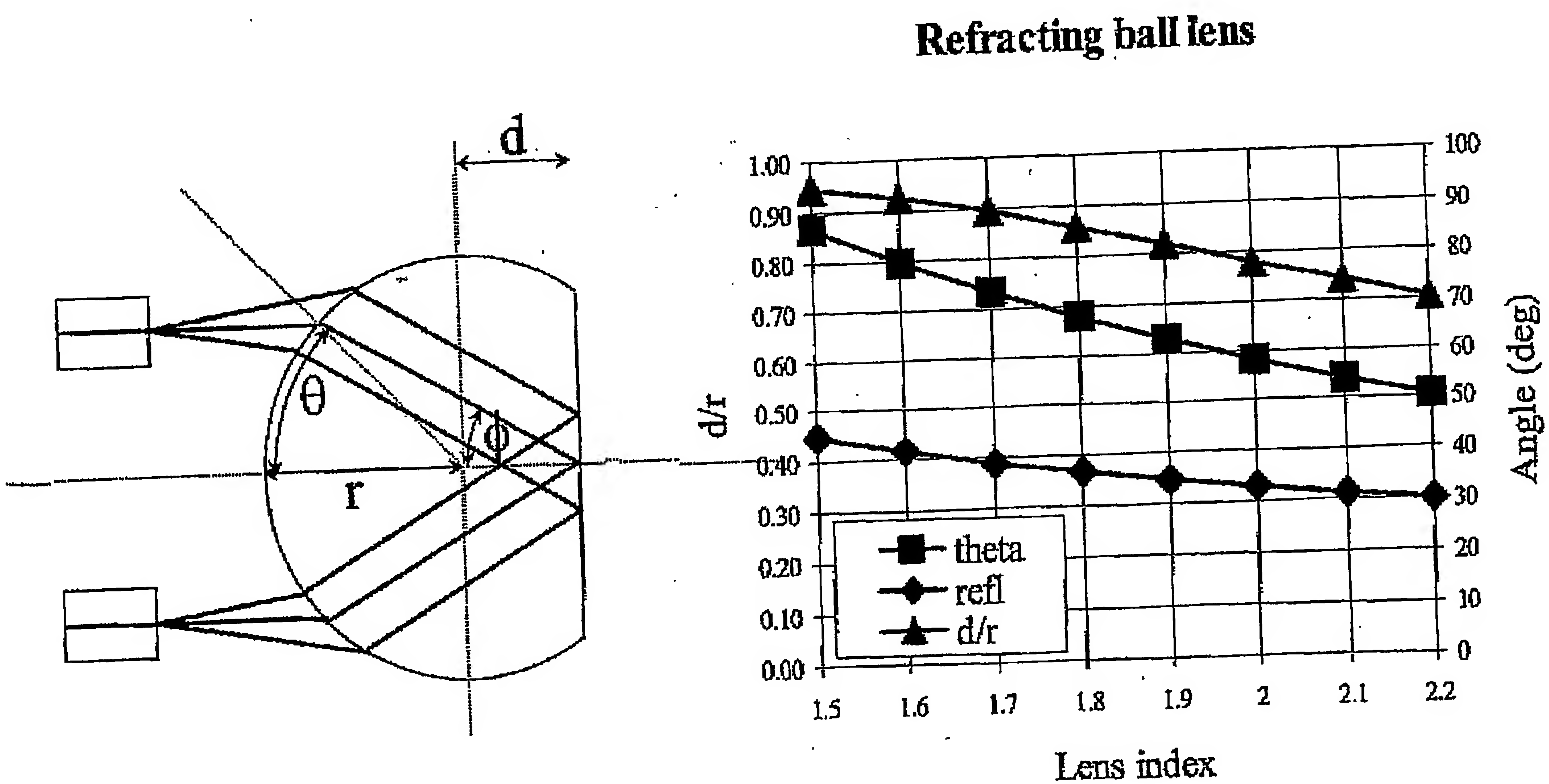

Unmated state
Air, vacuum, low index
High index ball lens
86
87
Protective film
Total internal reflection
at glass-air interface

FIG. 10b


d
θ
φ
r
Refracting ball lens
d/r
Angle (deg)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
100
90
80
70
60
50
40
30
20
10
0
theta
refl
d/r
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
Lens index

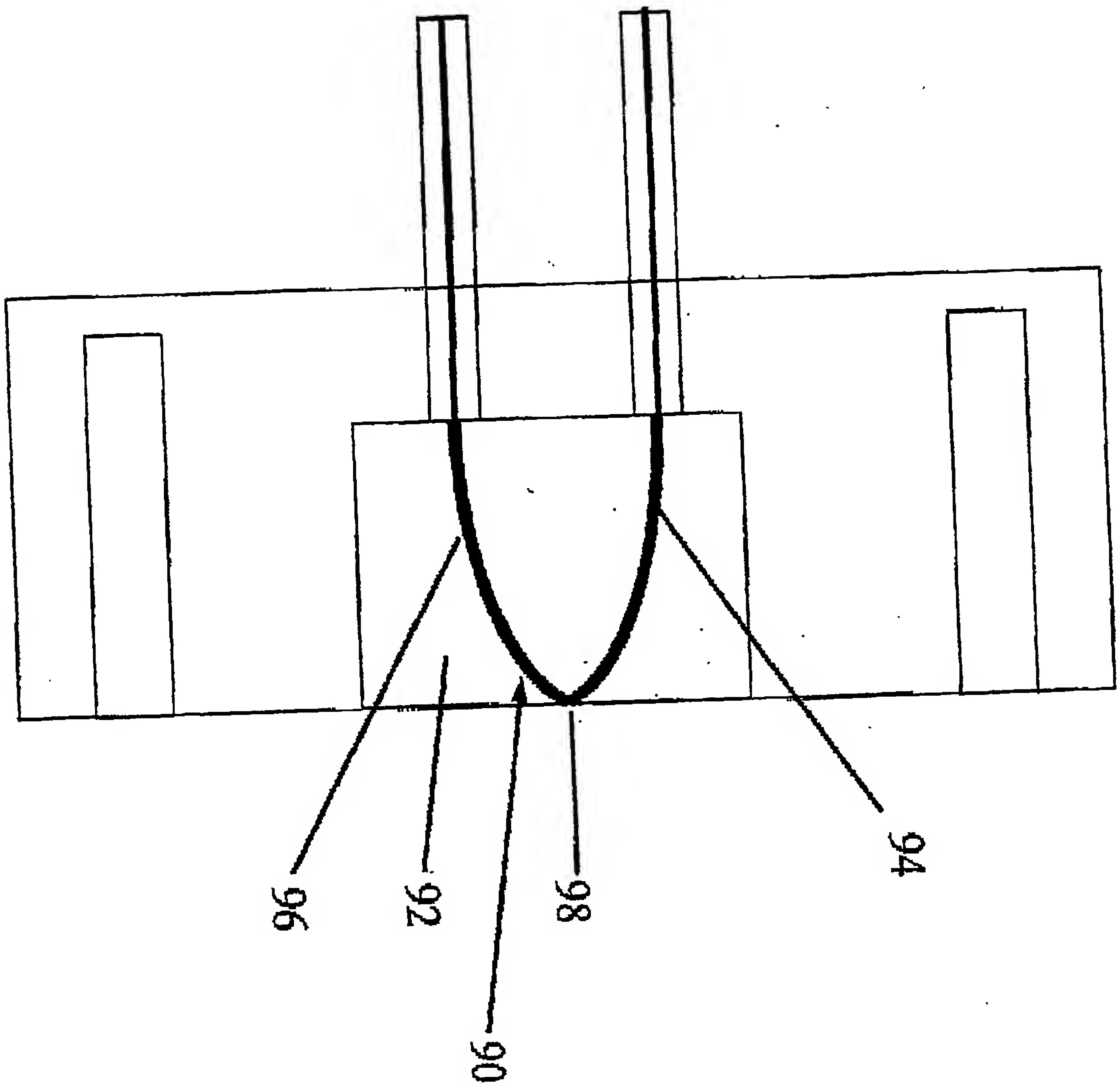
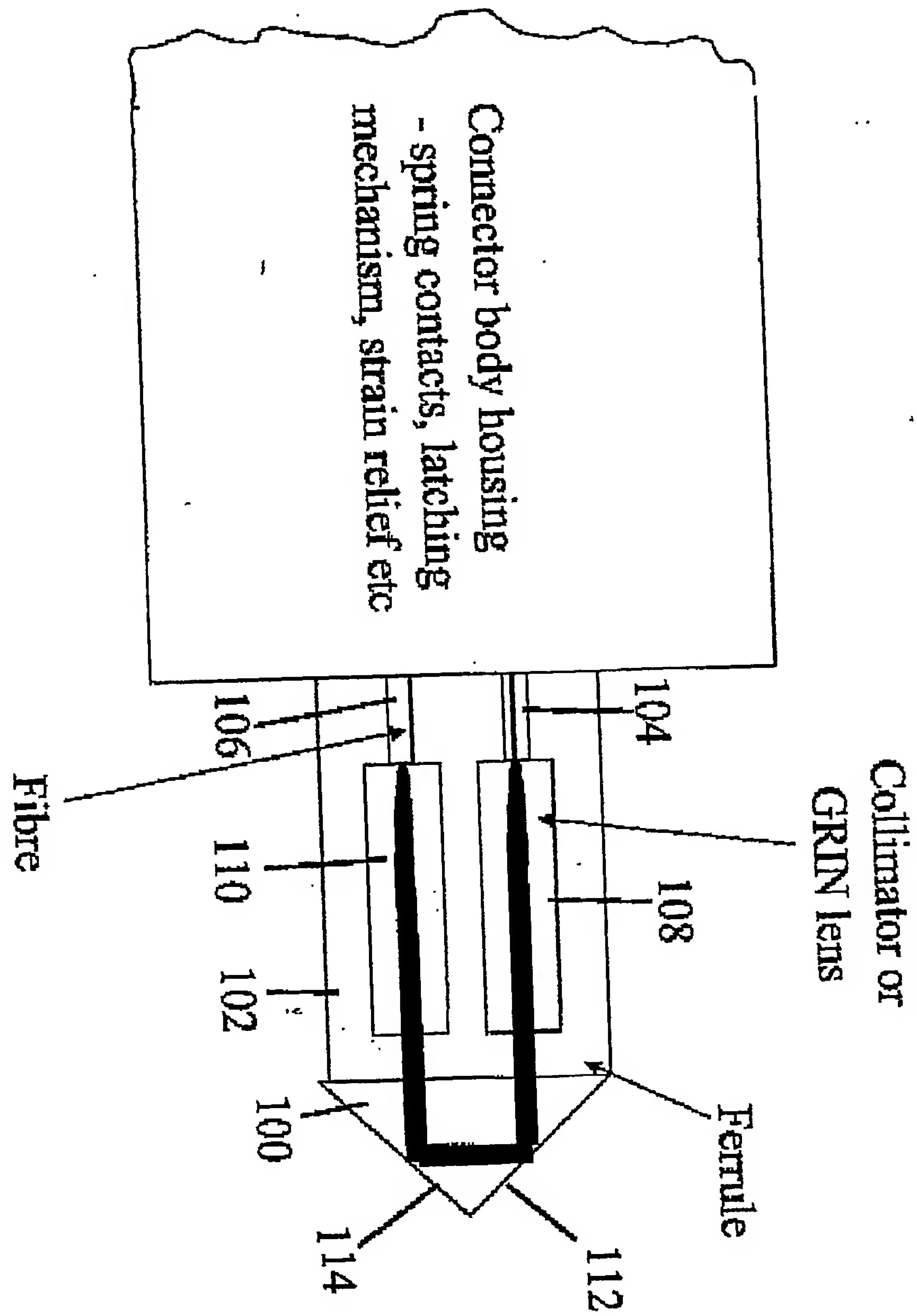


FIG. 11

FIG. 12


Connector body housing
- spring contacts, latching
mechanism, strain relief etc
104
106
Fibre
Collimator or
GRIN lens
108
110
102
100
Ferrule
114
112

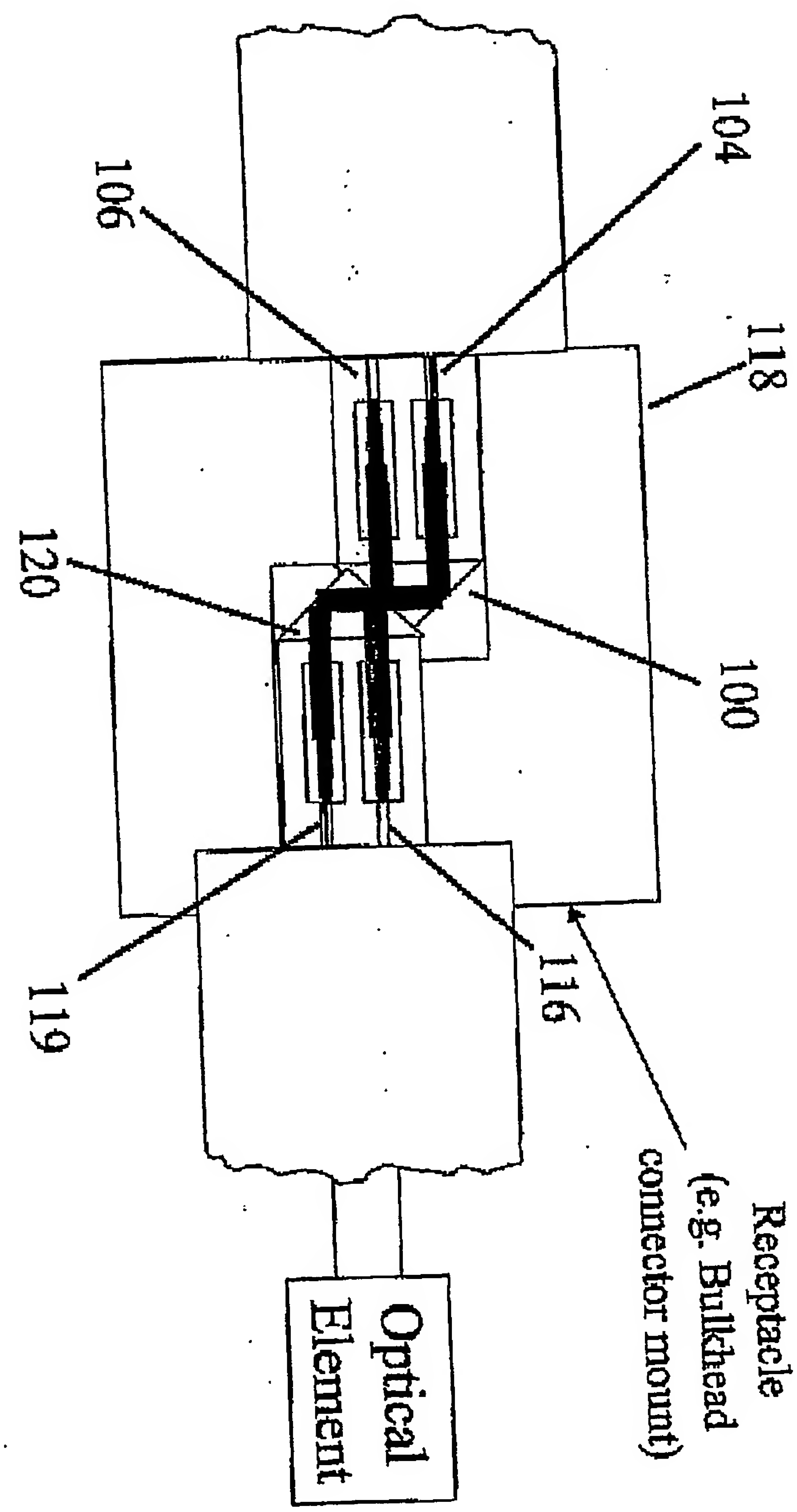

104
106
118
120
100
119
116
Receptacle
(e.g. Bulkhead
connector mount)
Optical
Element

FIG. 13

FIG. 14

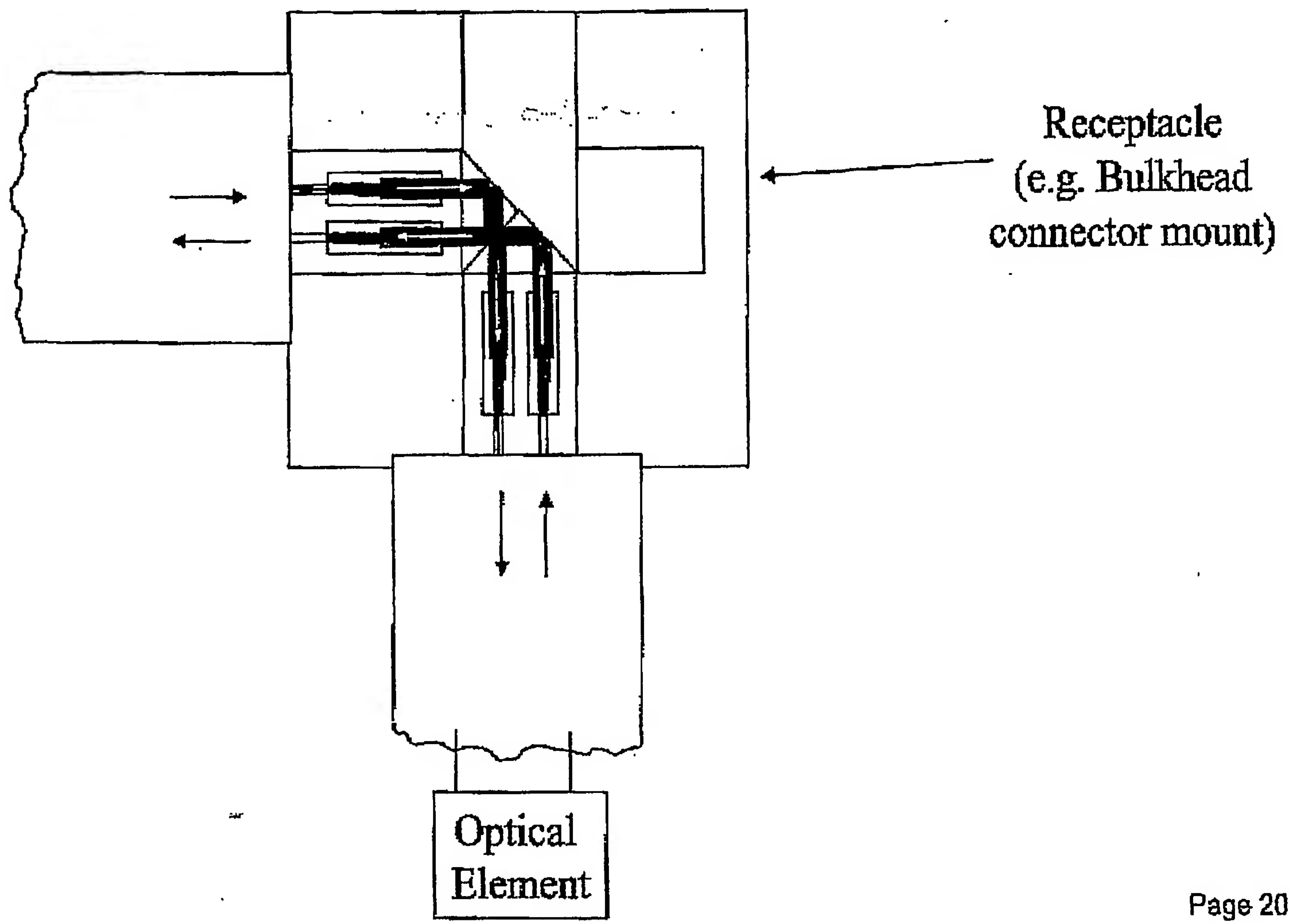


FIG. 15

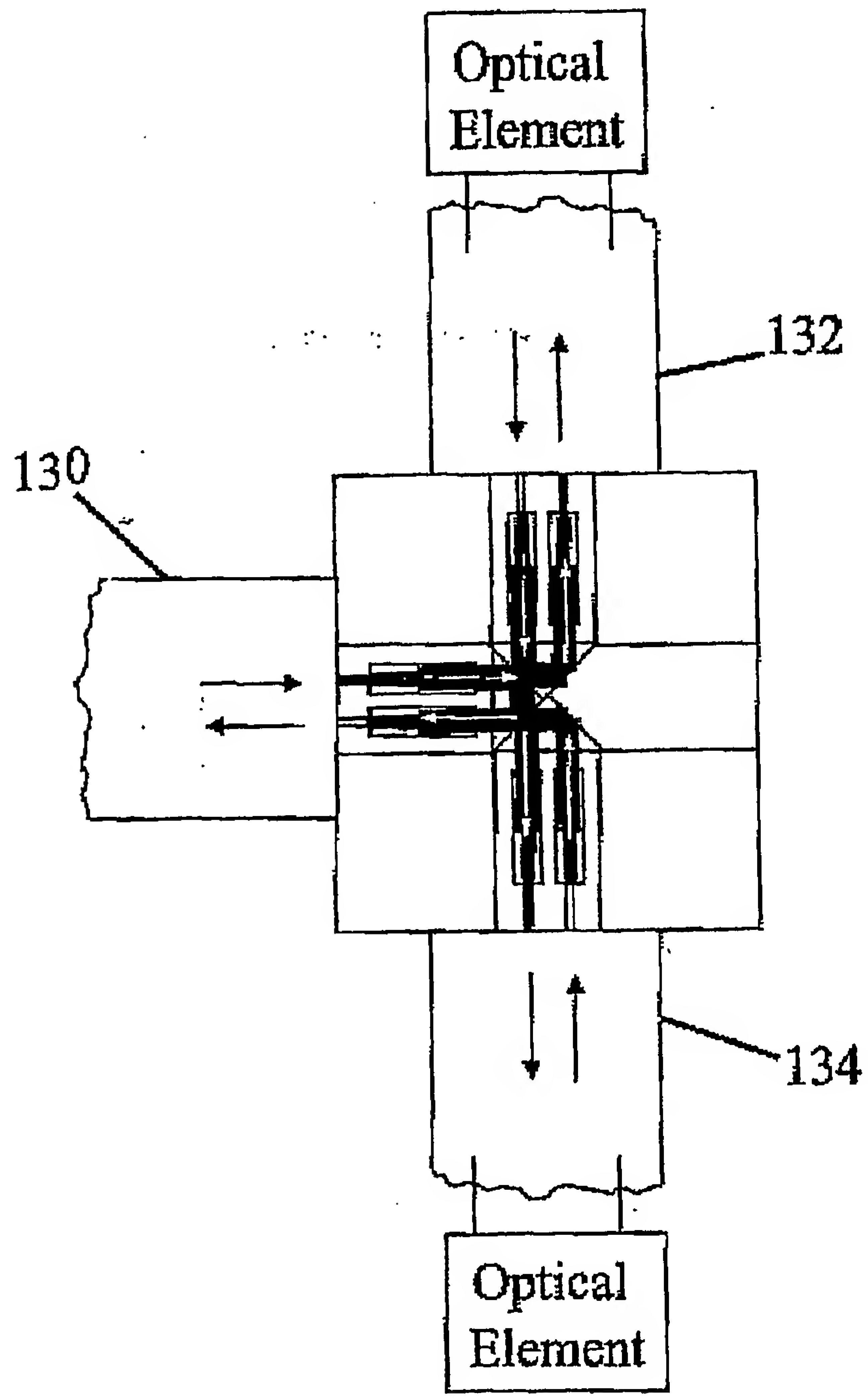


FIG. 16

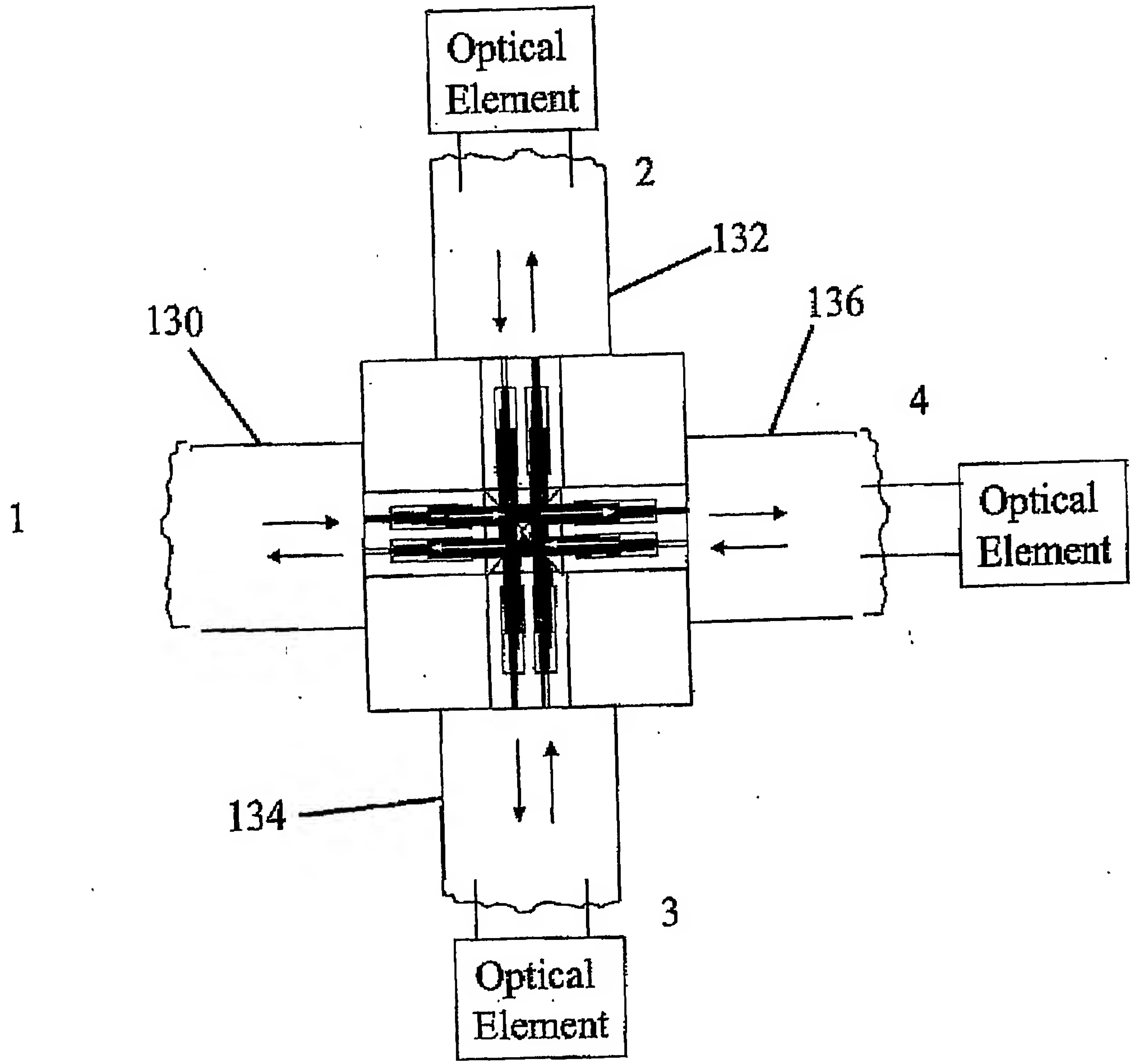

Optical Element
Optical Element
Optical Element
1
2
3
4
130
132
134
136

FIG .17

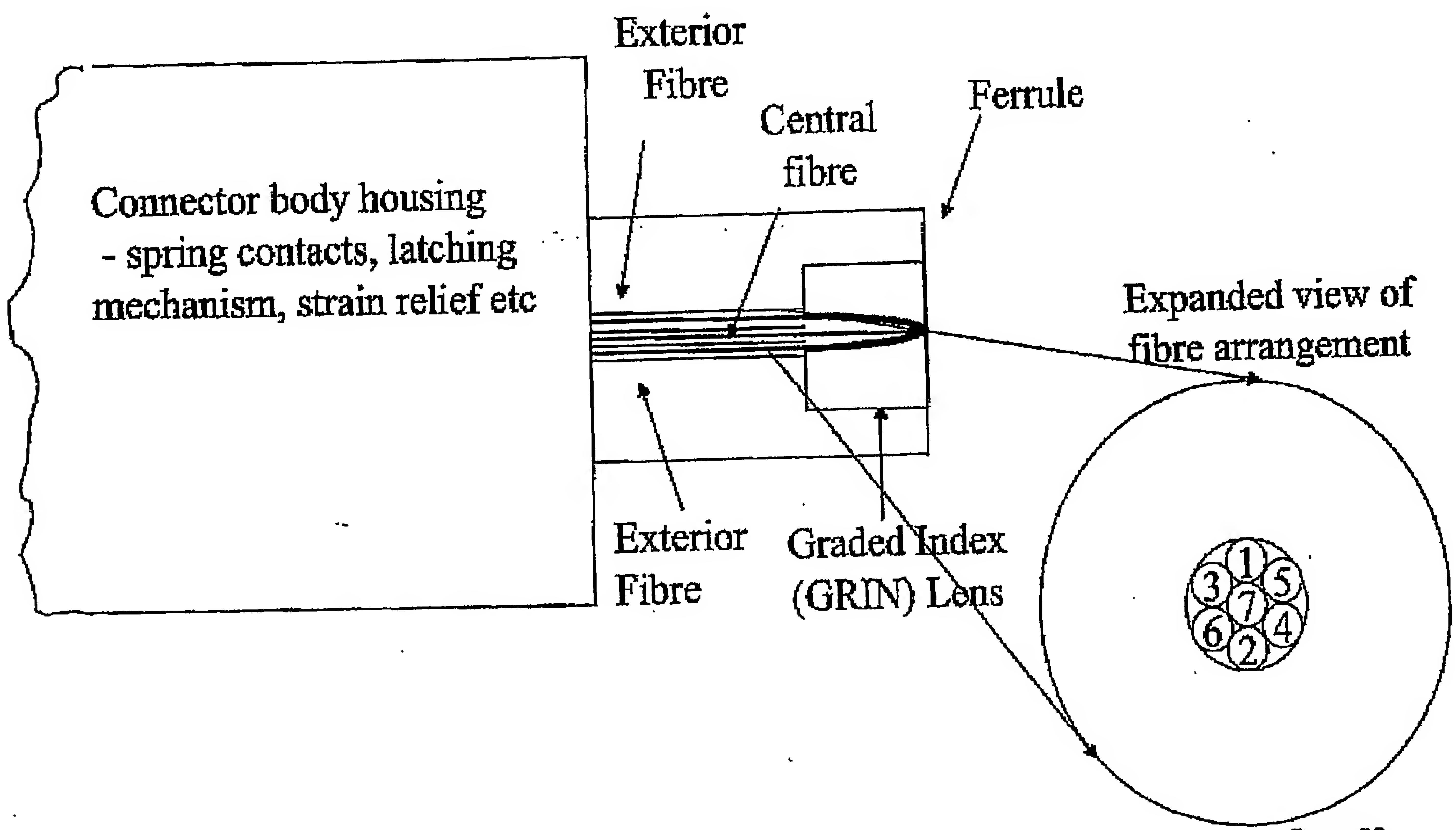

Exterior
Fibre
Central
fibre
Ferrule
Connector body housing
- spring contacts, latching
mechanism, strain relief etc
Expanded view of
fibre arrangement
Exterior
Fibre
Graded Index
(GRIN) Lens
1
3
5
7
6
4
2

FIG. 18

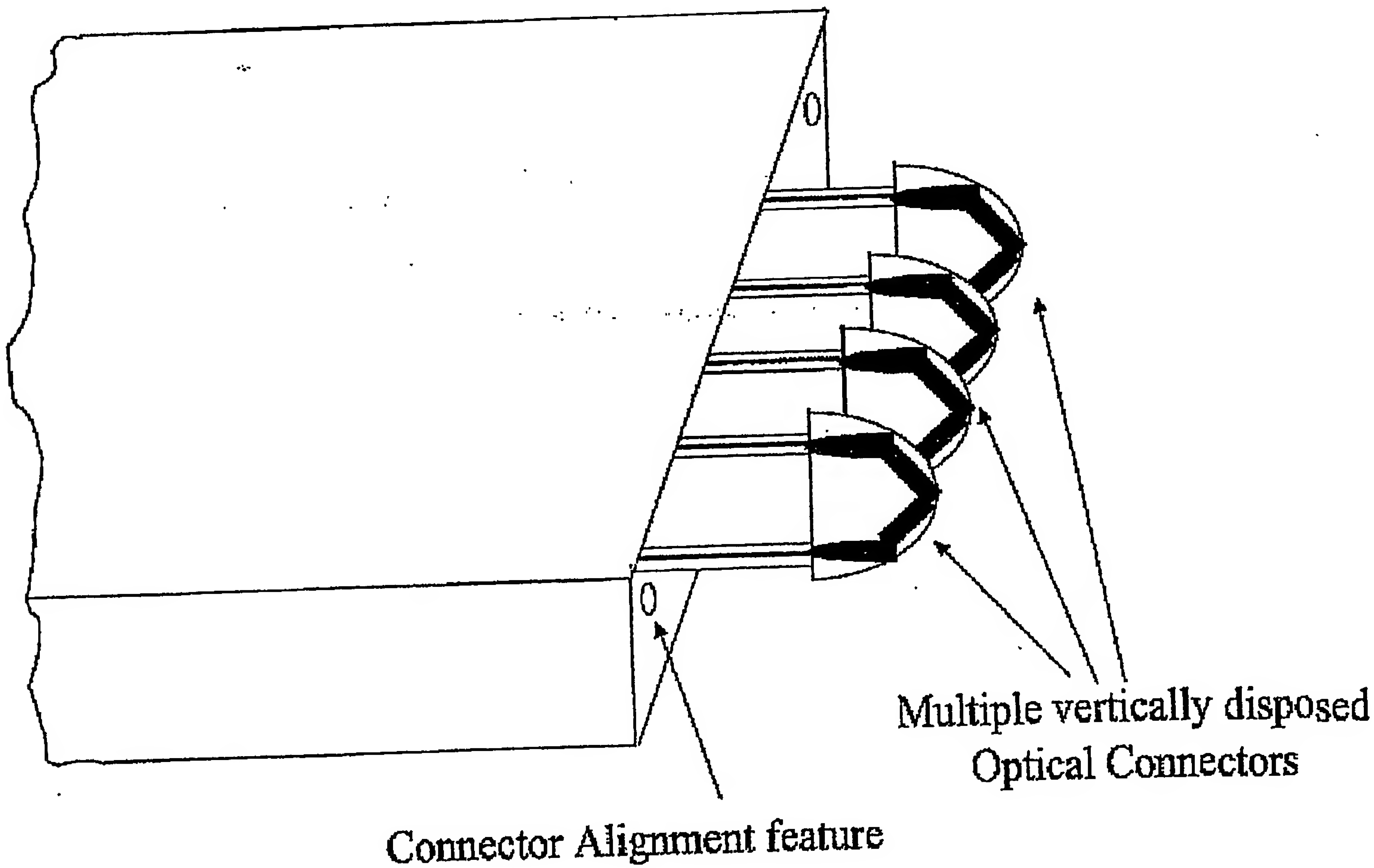
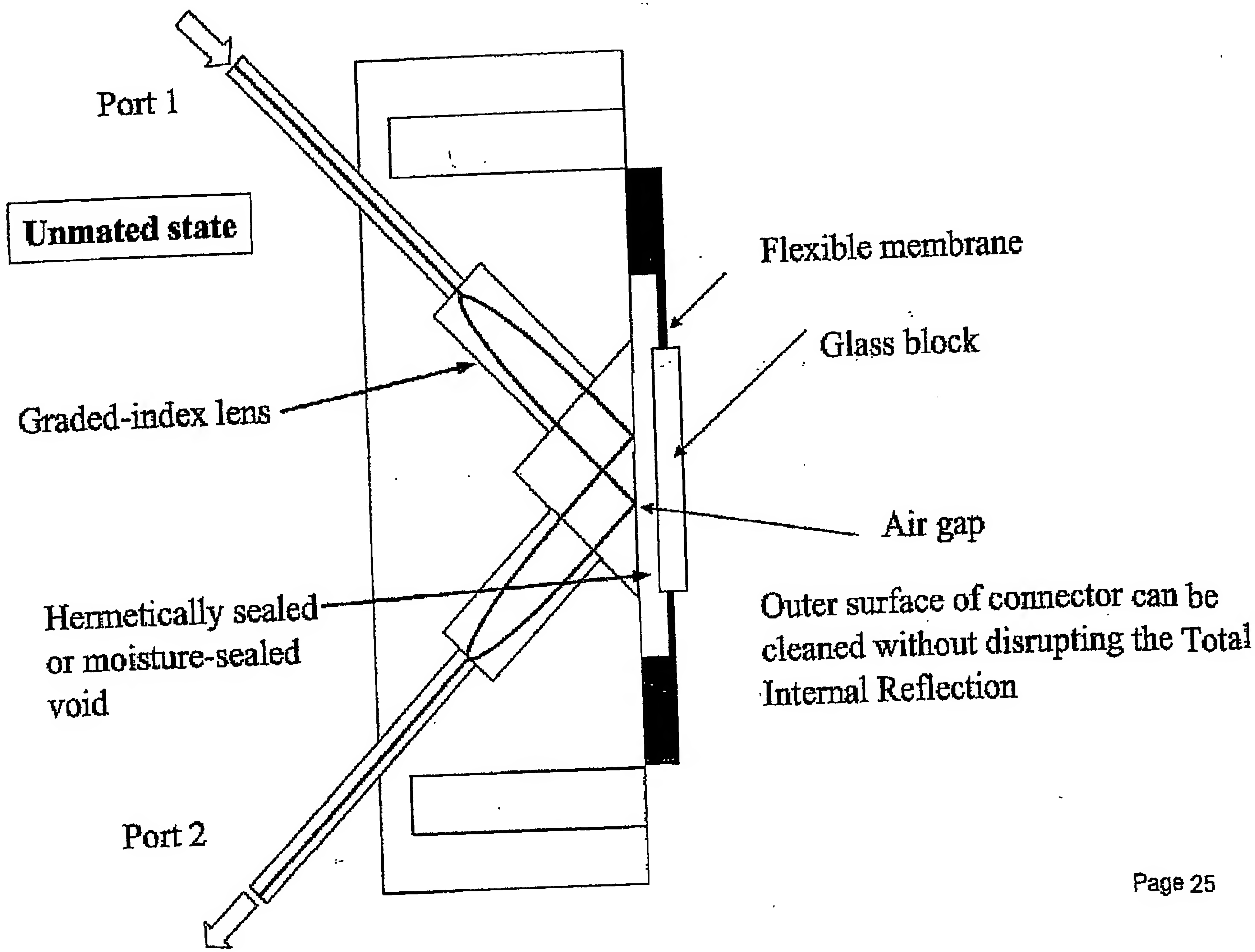

Multiple vertically disposed
Optical Connectors
Connector Alignment feature

FIG. 19


Port 1
Unmated state
Graded-index lens
Hermetically sealed
or moisture-sealed
void
Port 2
Flexible membrane
Glass block
Air gap
Outer surface of connector can be
cleaned without disrupting the Total
Internal Reflection

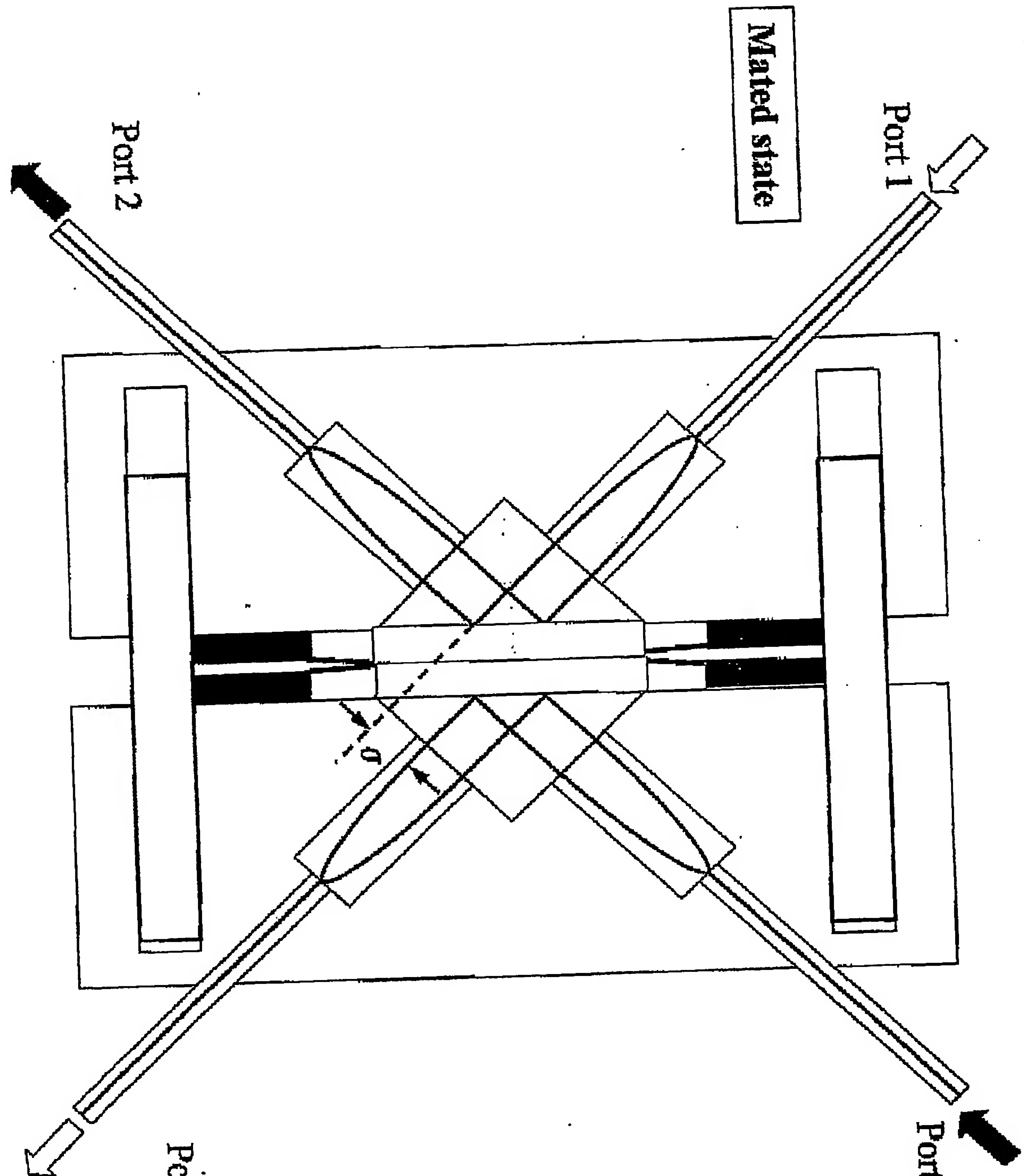
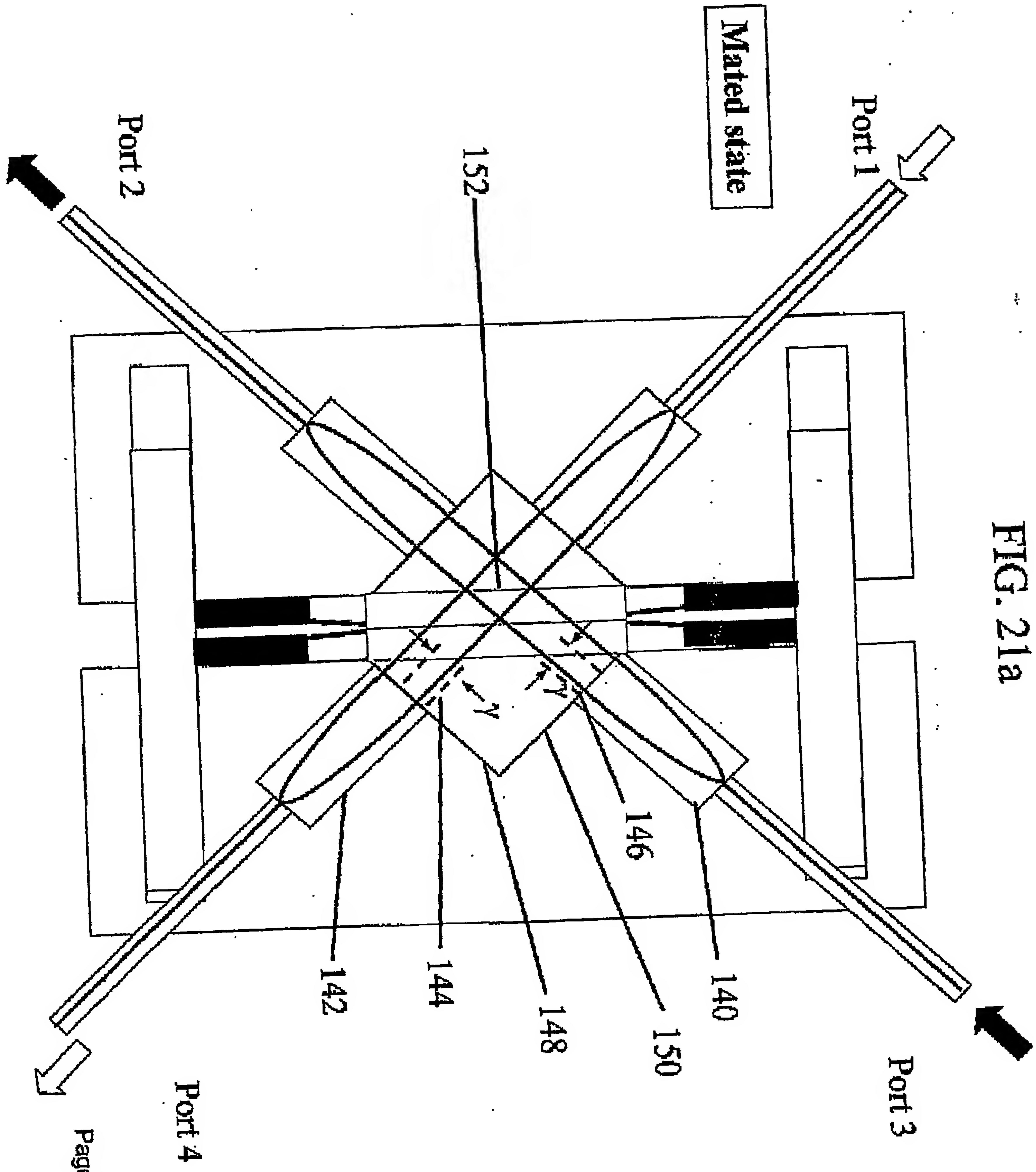


FIG. 20



Mated state
Port 1
Port 2
Port 3
Port 4
152
146
140
142
144
148
150
γ

FIG. 21a

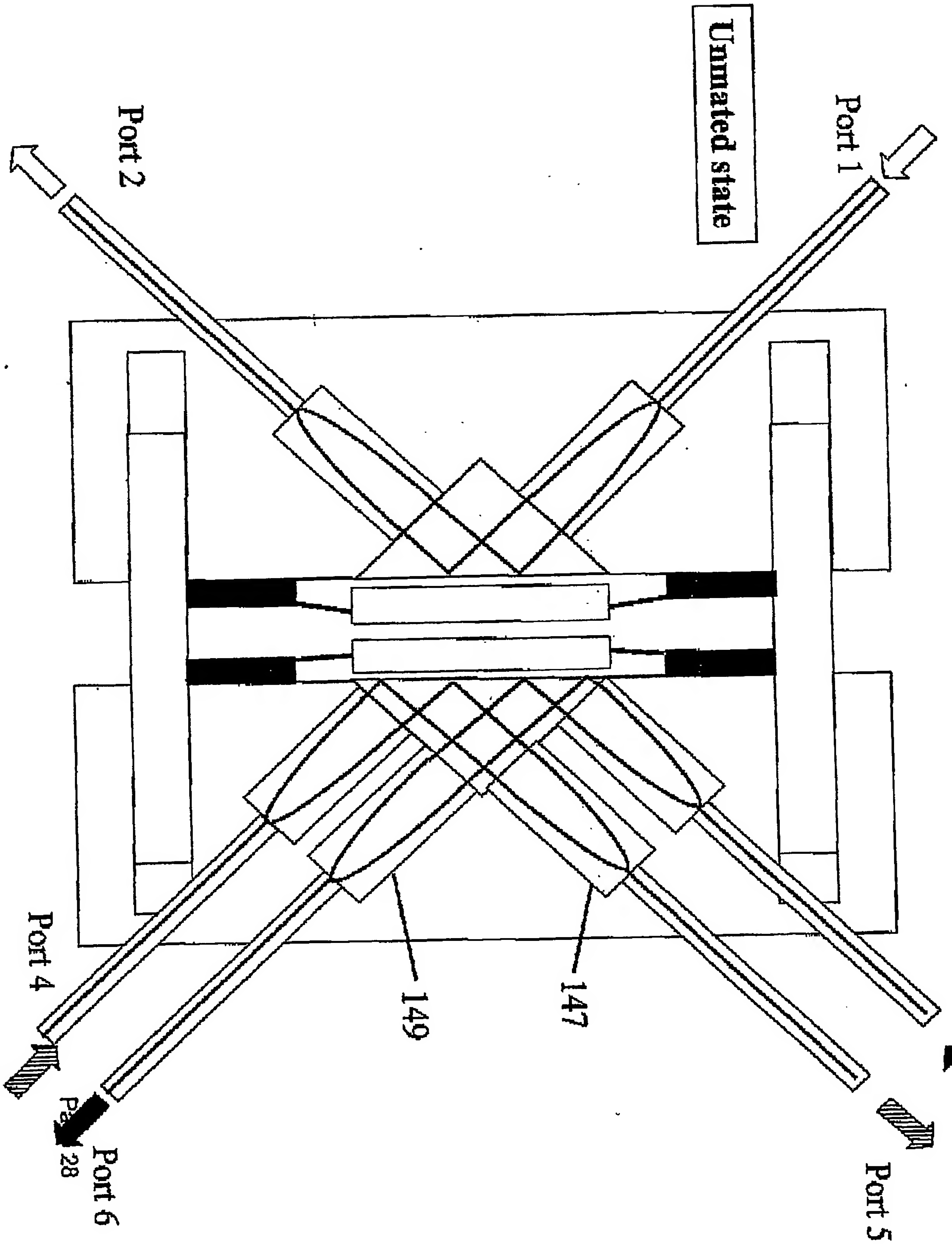


FIG. 21b

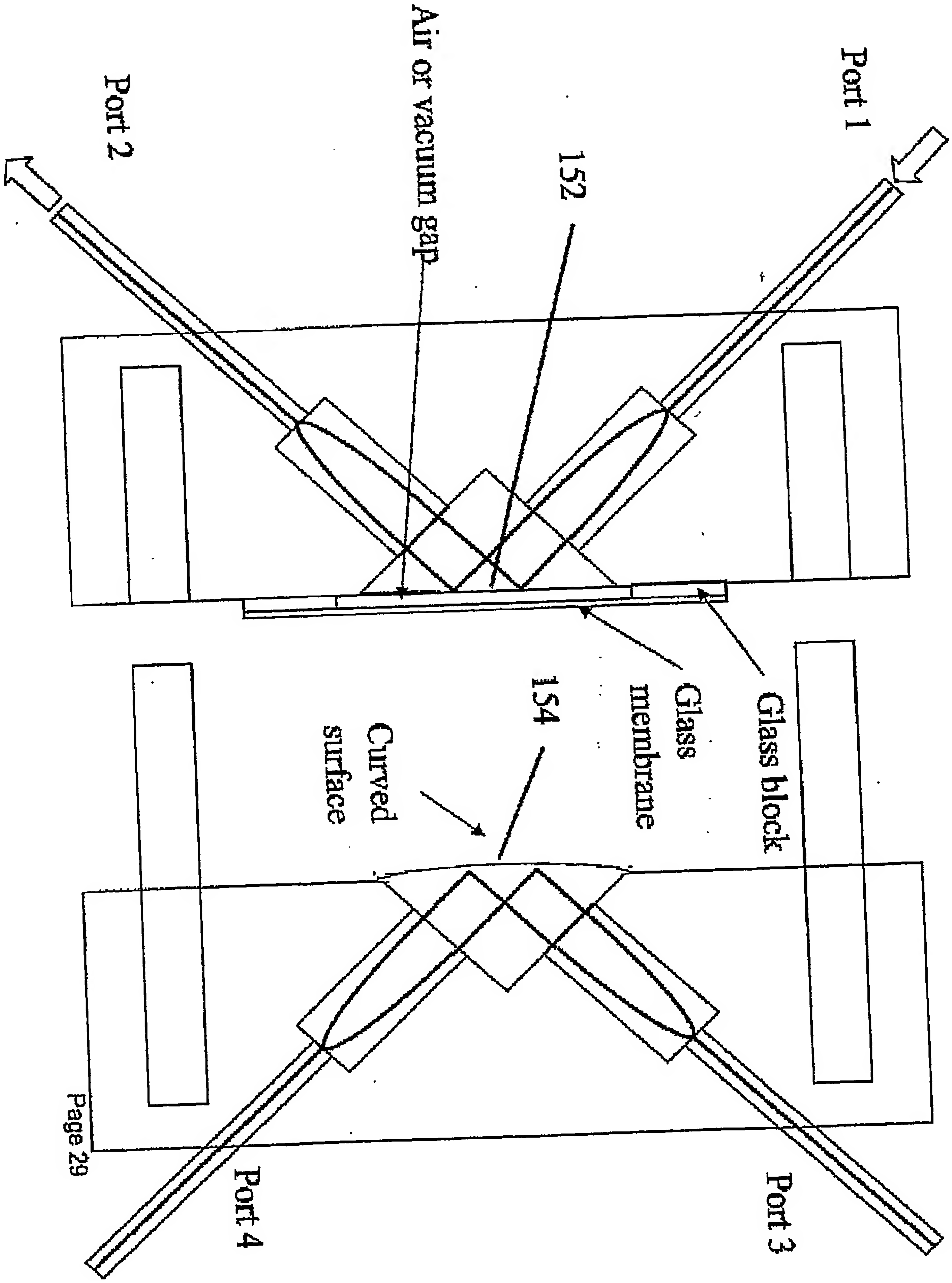

Port 1
Port 2
Air or vacuum gap
152
Glass block
Glass membrane
154
Curved surface
Port 3
Port 4

FIG. 22

FIG. 23

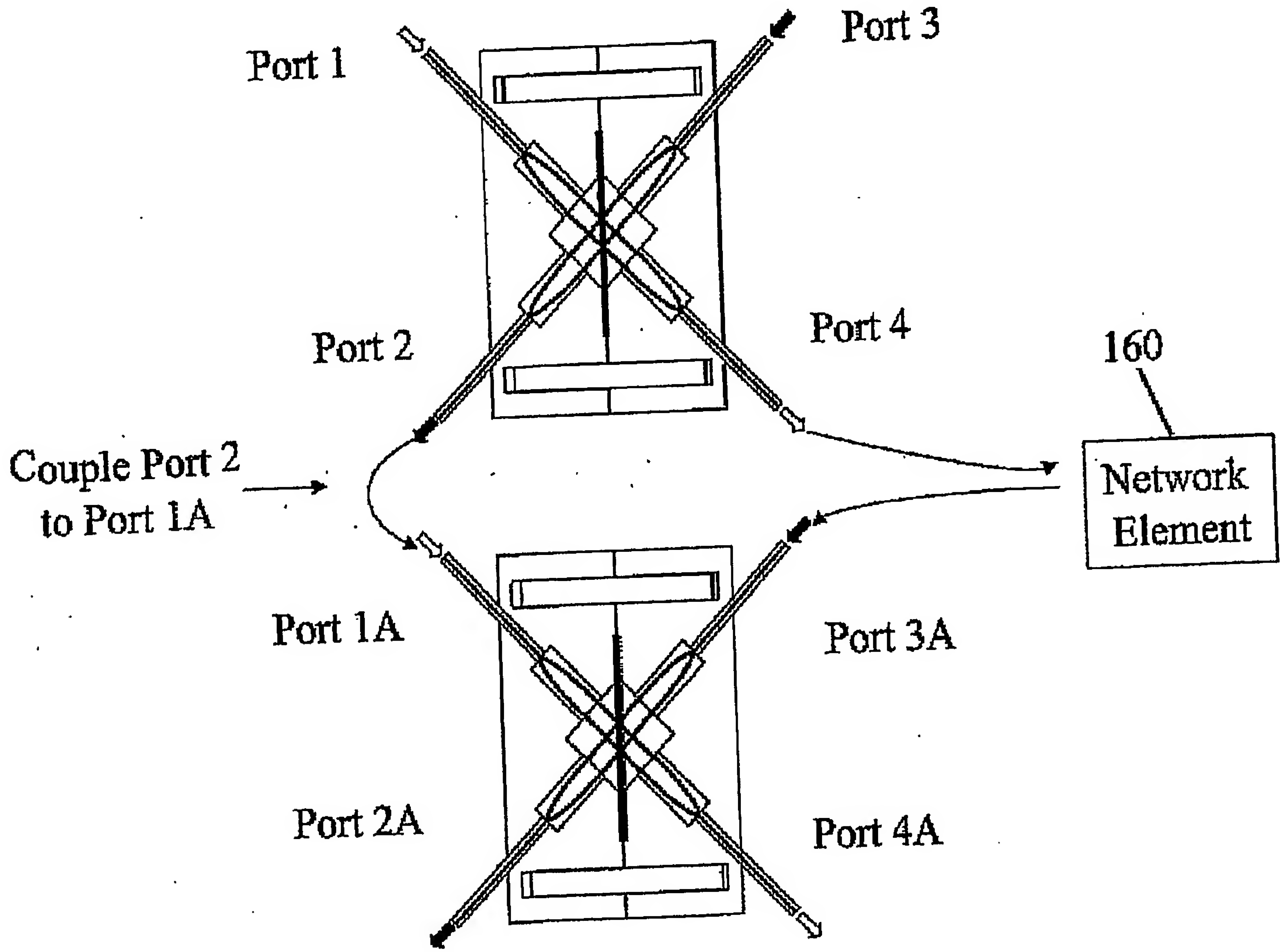

Port 1
Port 3
Port 2
Port 4
160
Couple Port 2
to Port 1A
Network
Element
Port 1A
Port 3A
Port 2A
Port 4A

FIG. 24

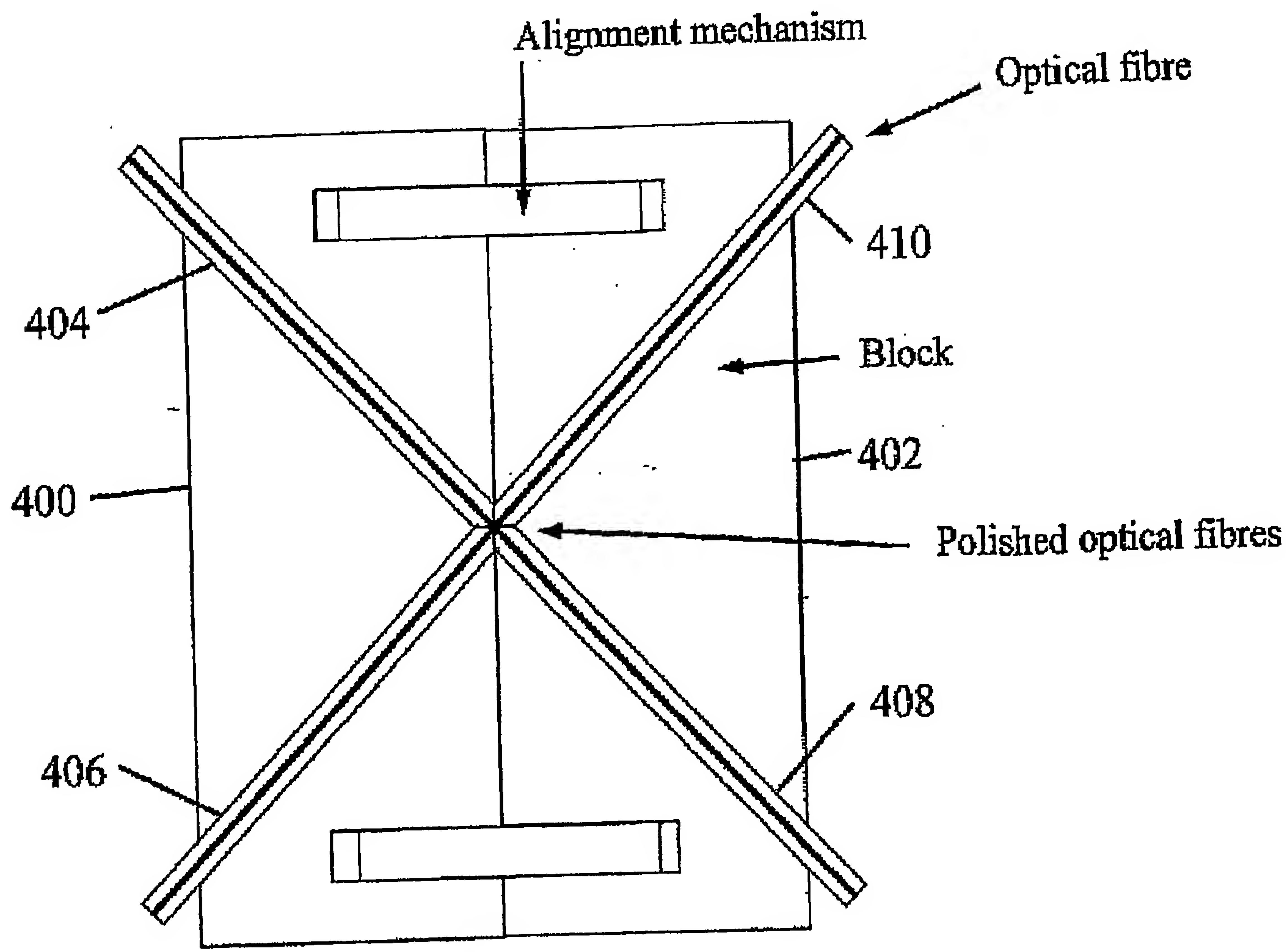
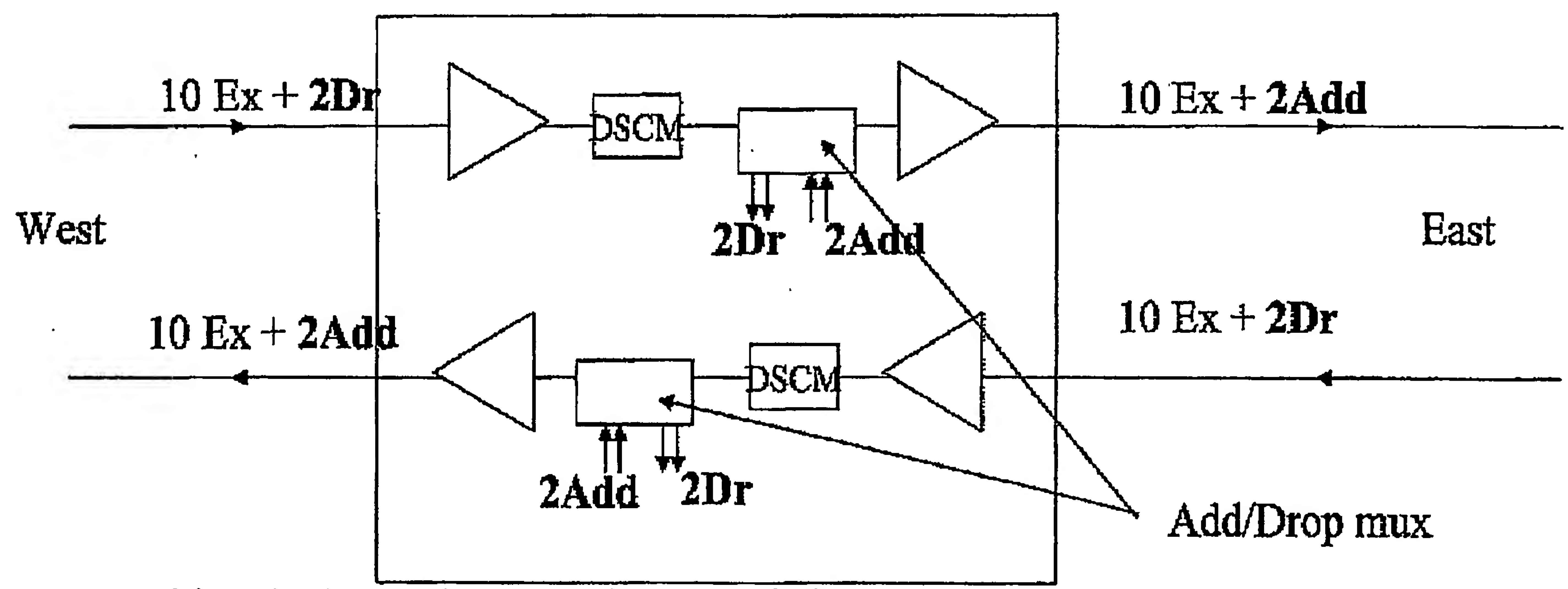

Alignment mechanism
Optical fibre
410
404
Block
402
400
Polished optical fibres
408
406

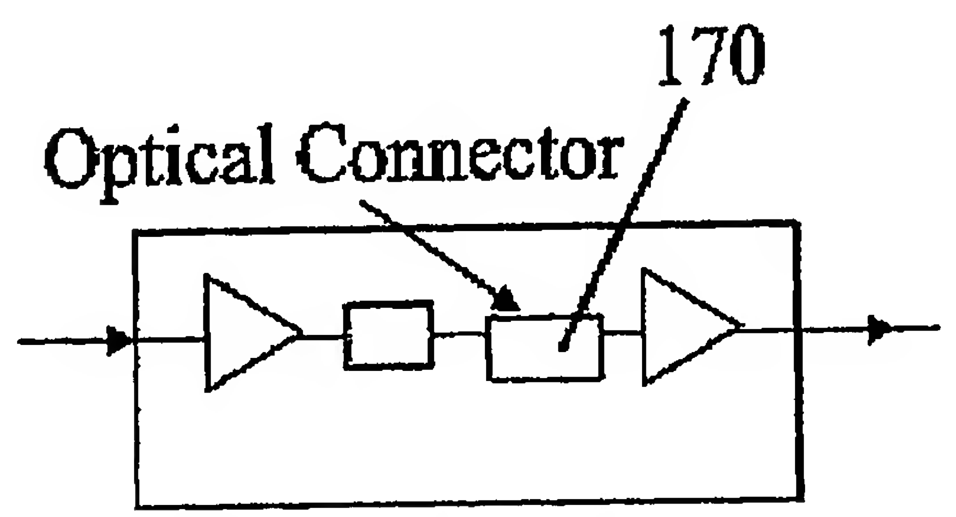
FIG. 25

- Lowest cost method of deploying Optical Metro and Regional systems with OADM is by using fixed filters

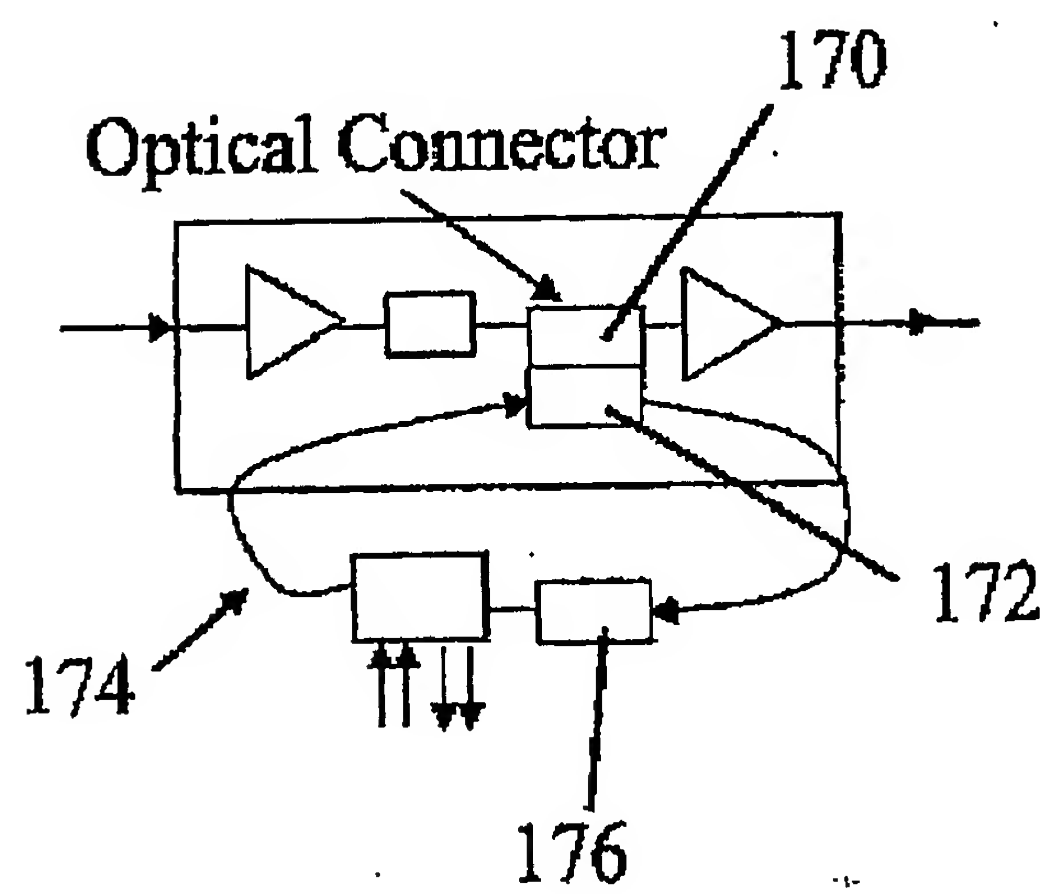


- Problem is that node cannot be upgraded to different OADM configuration without interrupting traffic

FIG. 26



Start with no OADM capability
Include Optical Connector (OC)

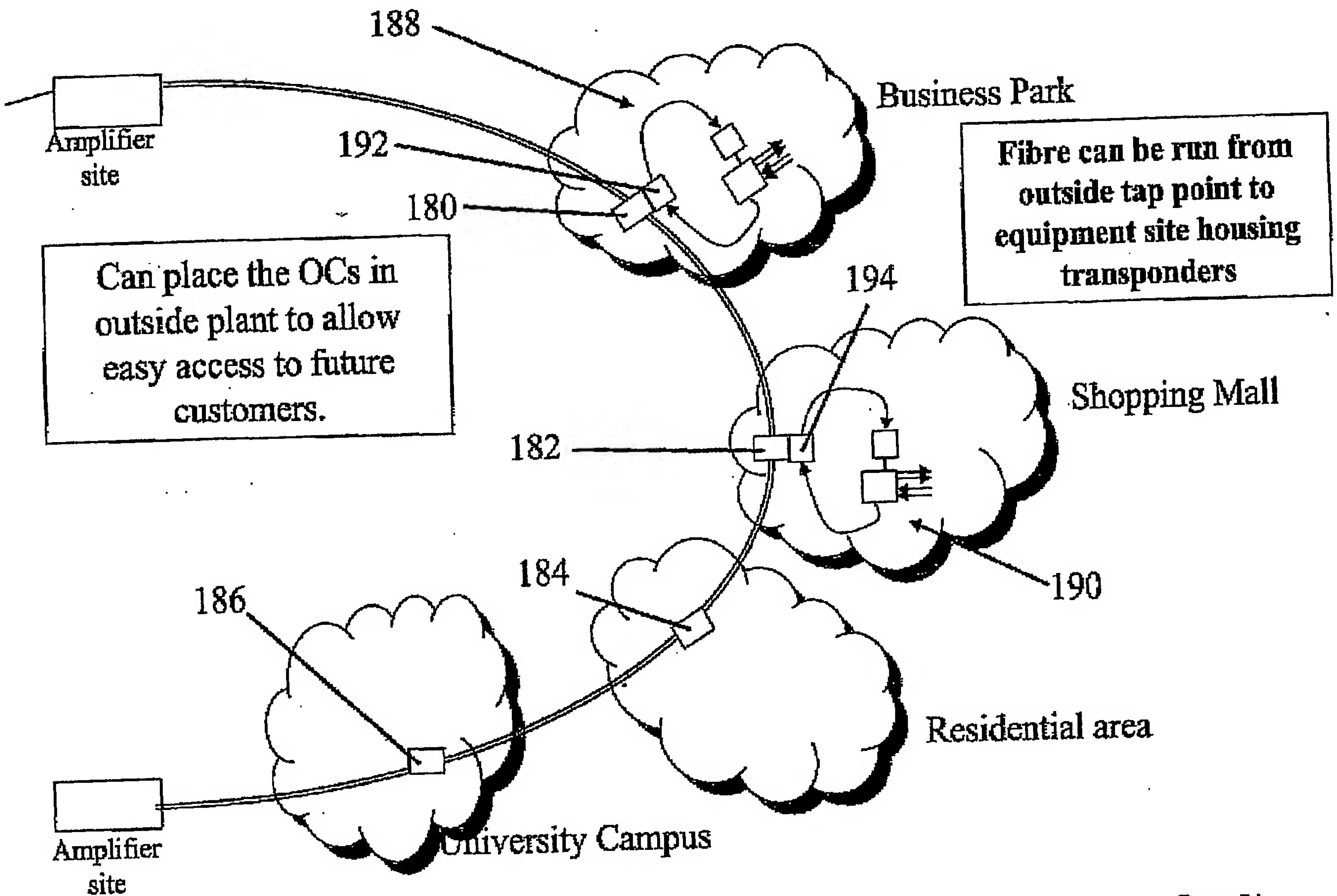


Connect OADM filter set, including additional OC

Connect second OADM filter set, including additional OC

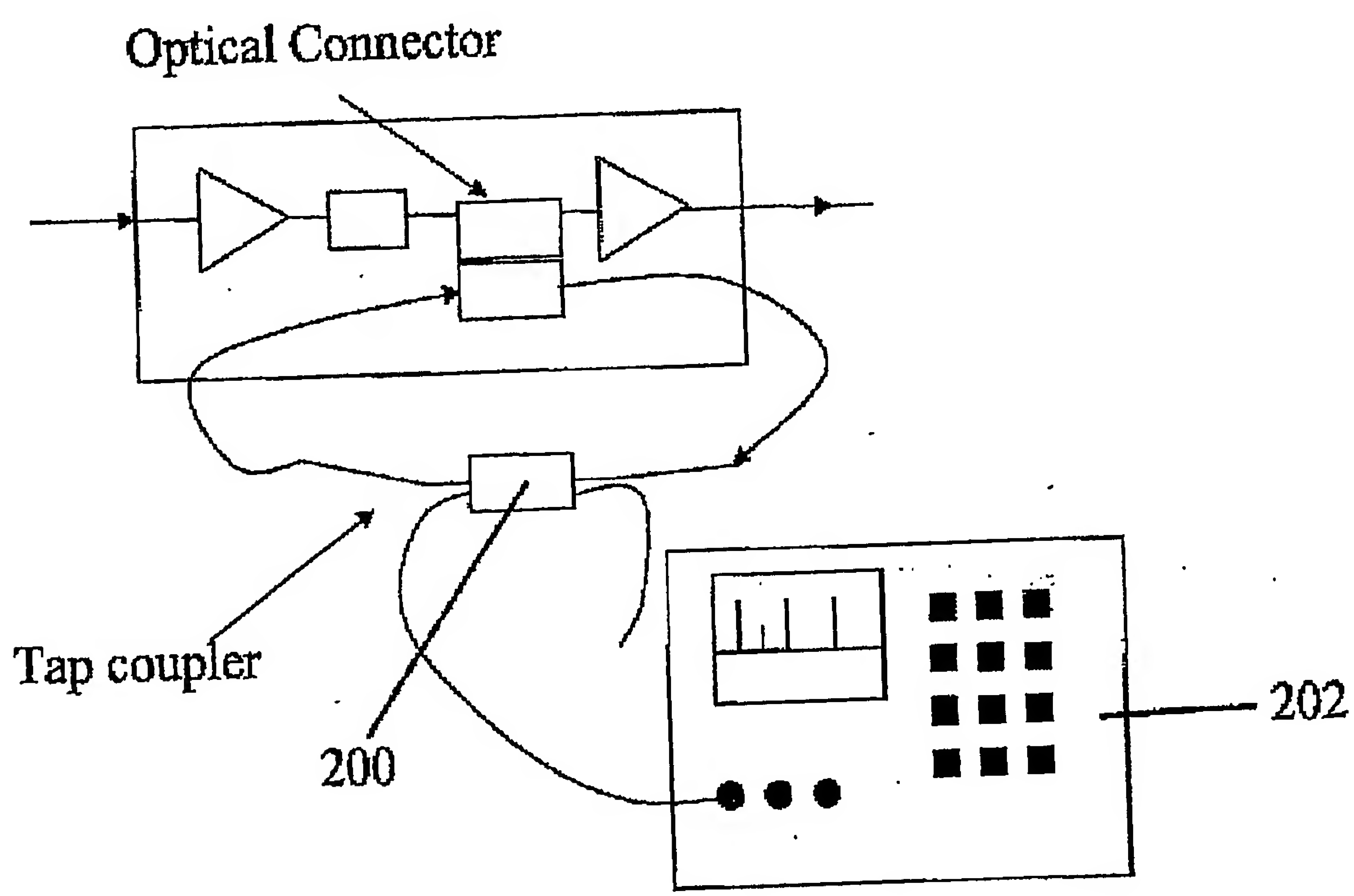
Advantage is that we can allocate wavelengths to nodes as required. Eliminates need for pre-planning of wavelength allocation.

FIG. 27



188
192
180
Amplifier site
Business Park
Fibre can be run from outside tap point to equipment site housing transponders
Can place the OCs in outside plant to allow easy access to future customers.
194
182
Shopping Mall
184
190
186
Residential area
Amplifier site
University Campus

FIG. 28



Can utilise Optical Connector together with a tap coupler (typically 1% - 10%) to couple measurement equipment onto operating system

FIG. 29

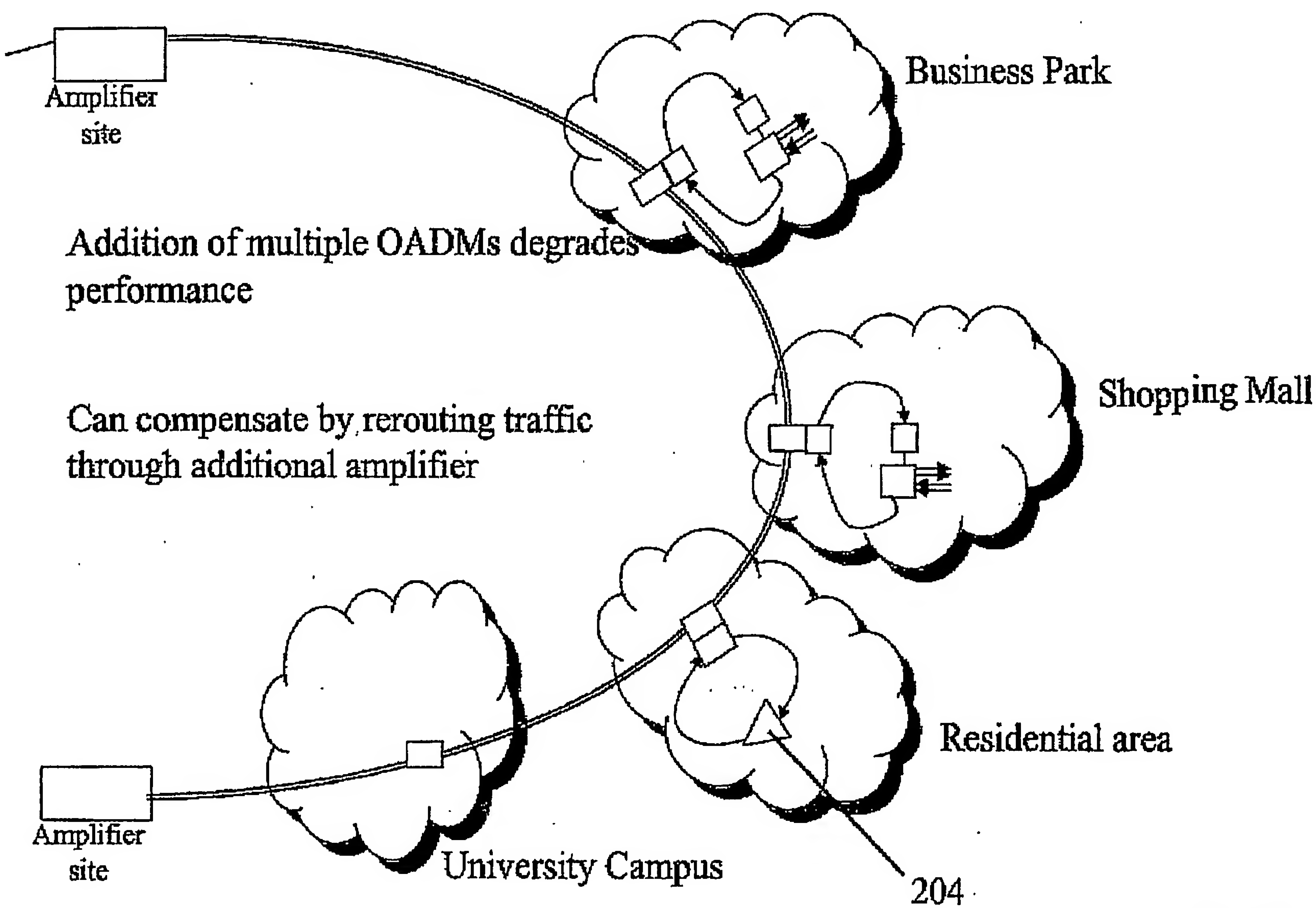
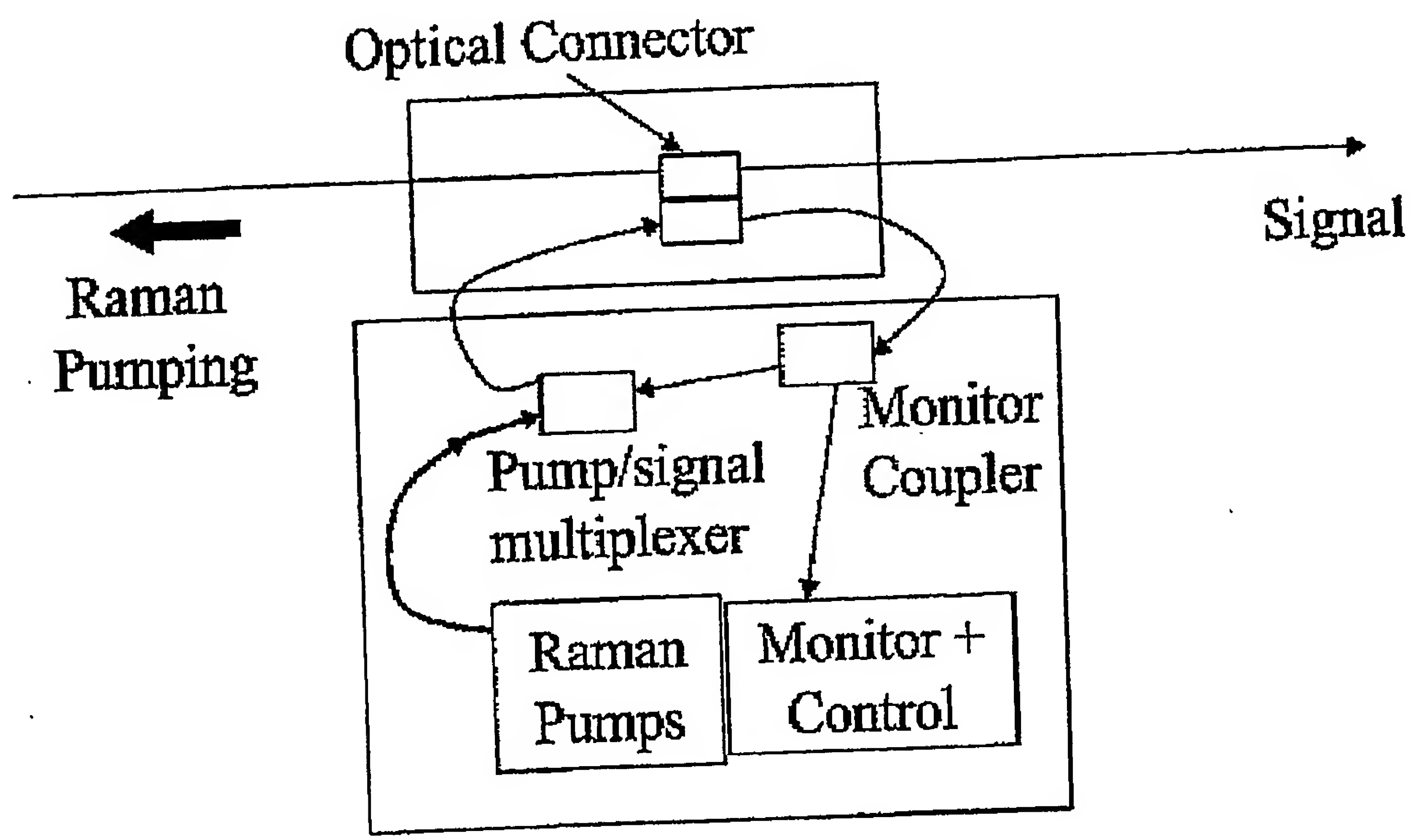

Amplifier site
Business Park
Addition of multiple OADMs degrades performance
Shopping Mall
Can compensate by rerouting traffic through additional amplifier
Residential area
Amplifier site
University Campus
204

FIG. 30

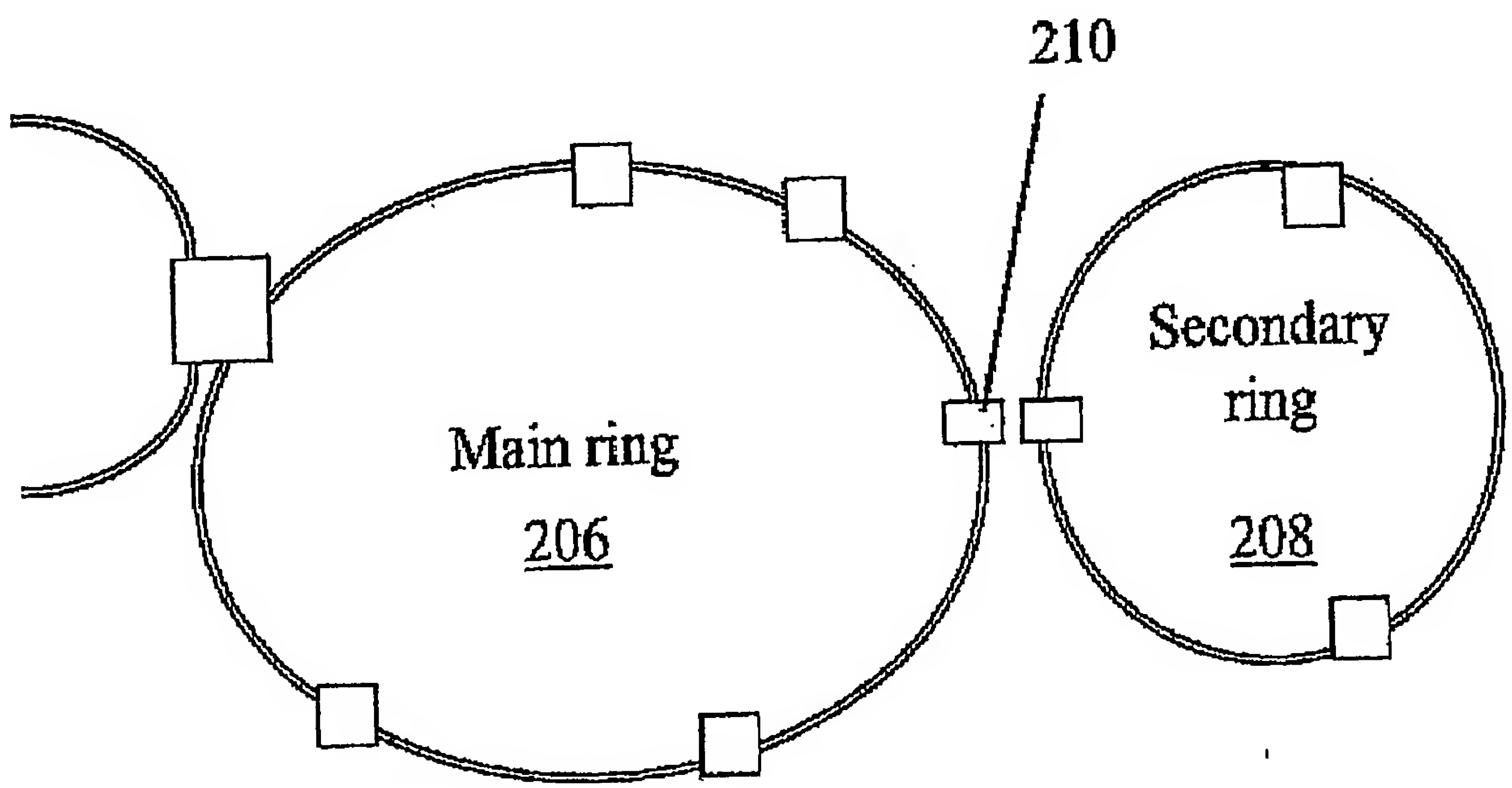


Add Raman Amplifier – advantage is low through loss for signal

Can turn up gain slowly, in service, without affecting traffic

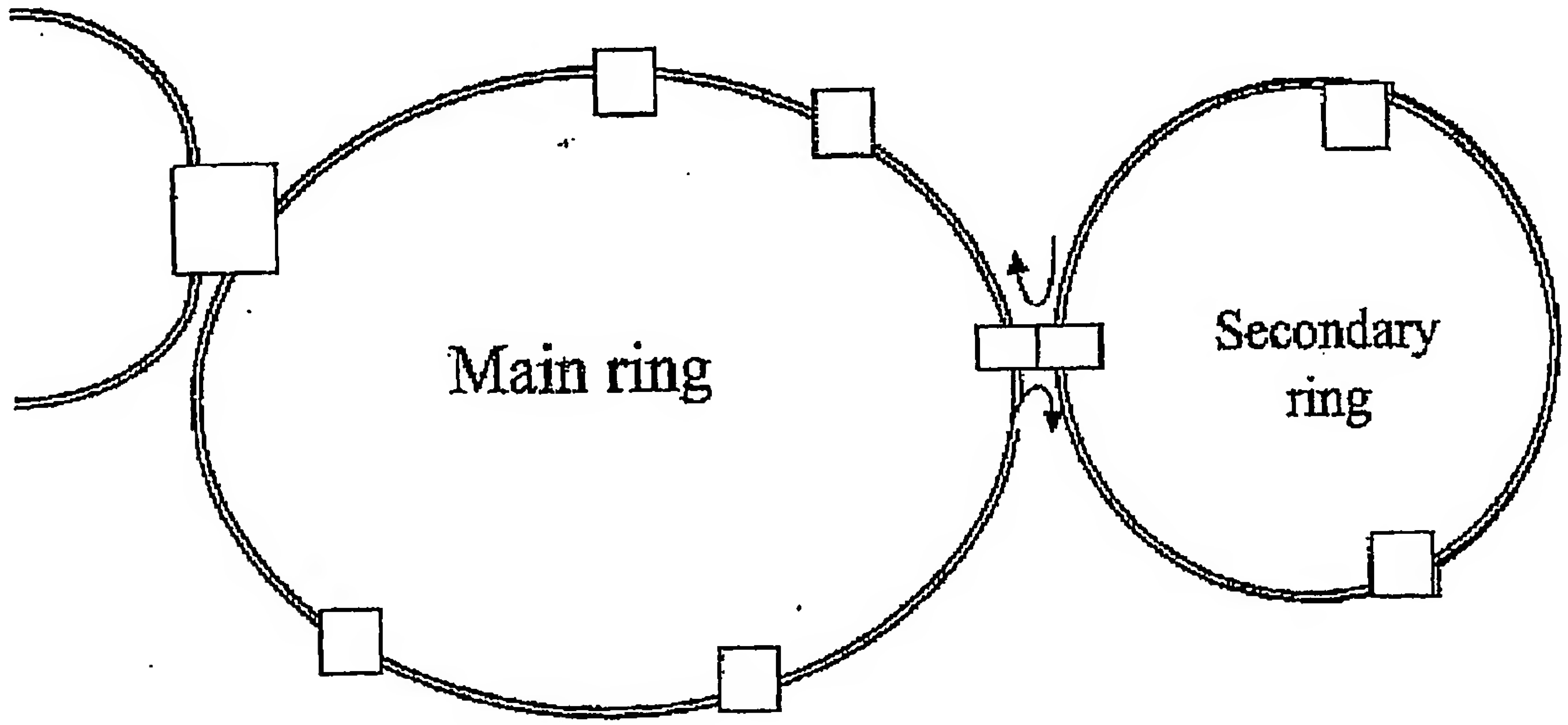
Expanded beam in Optical Connector capable of handling high power

FIG. 31a



A secondary ring can be commissioned and then both rings merged using Optical Connector

FIG. 31b



1) Reroute traffic at nodes adjacent to Optical Connector

2) Join rings to create single large ring

3) Commission new paths through enlarged ring

4) Switch to new paths through enlarged ring

FIG. 32

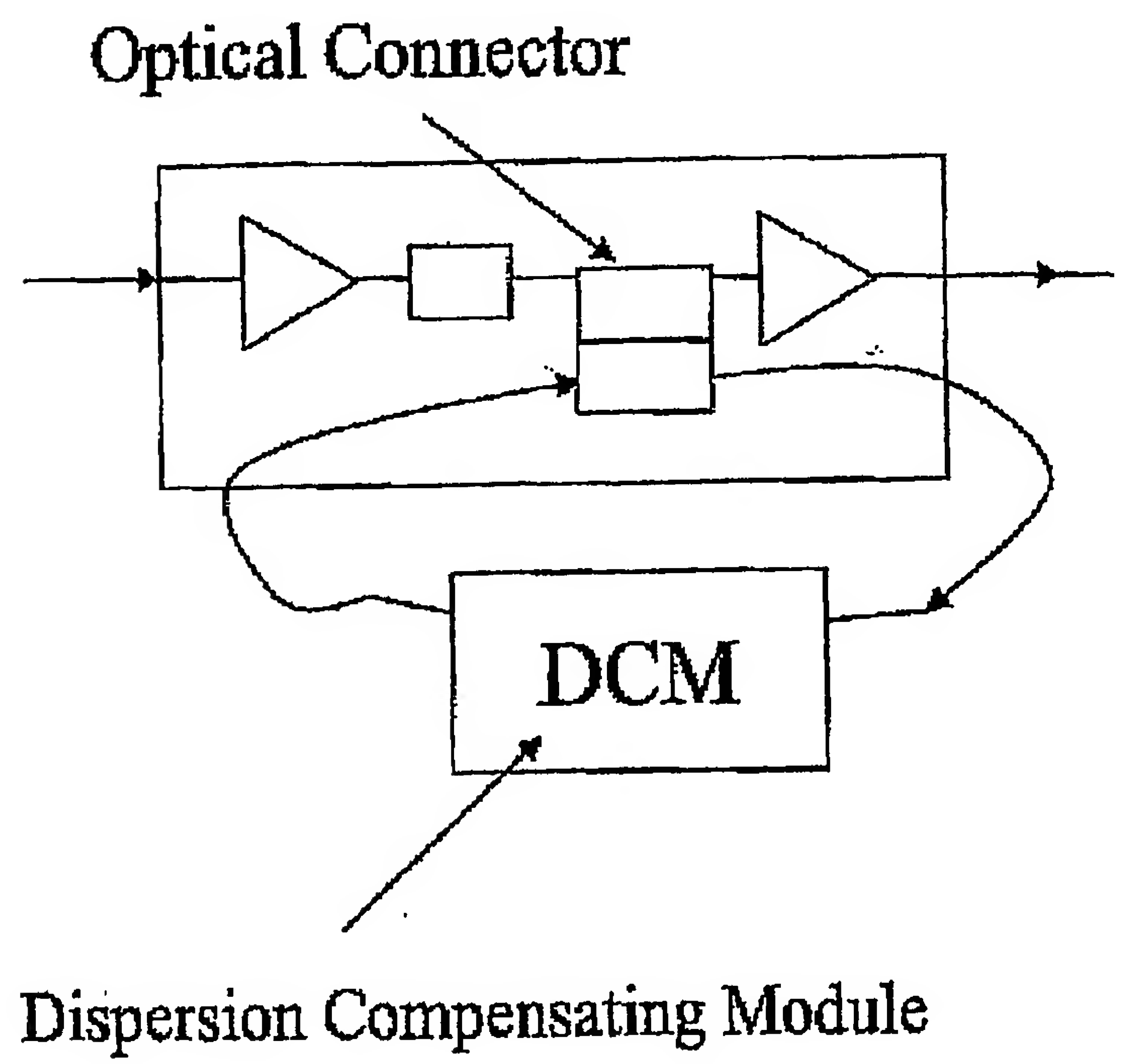


FIG. 33

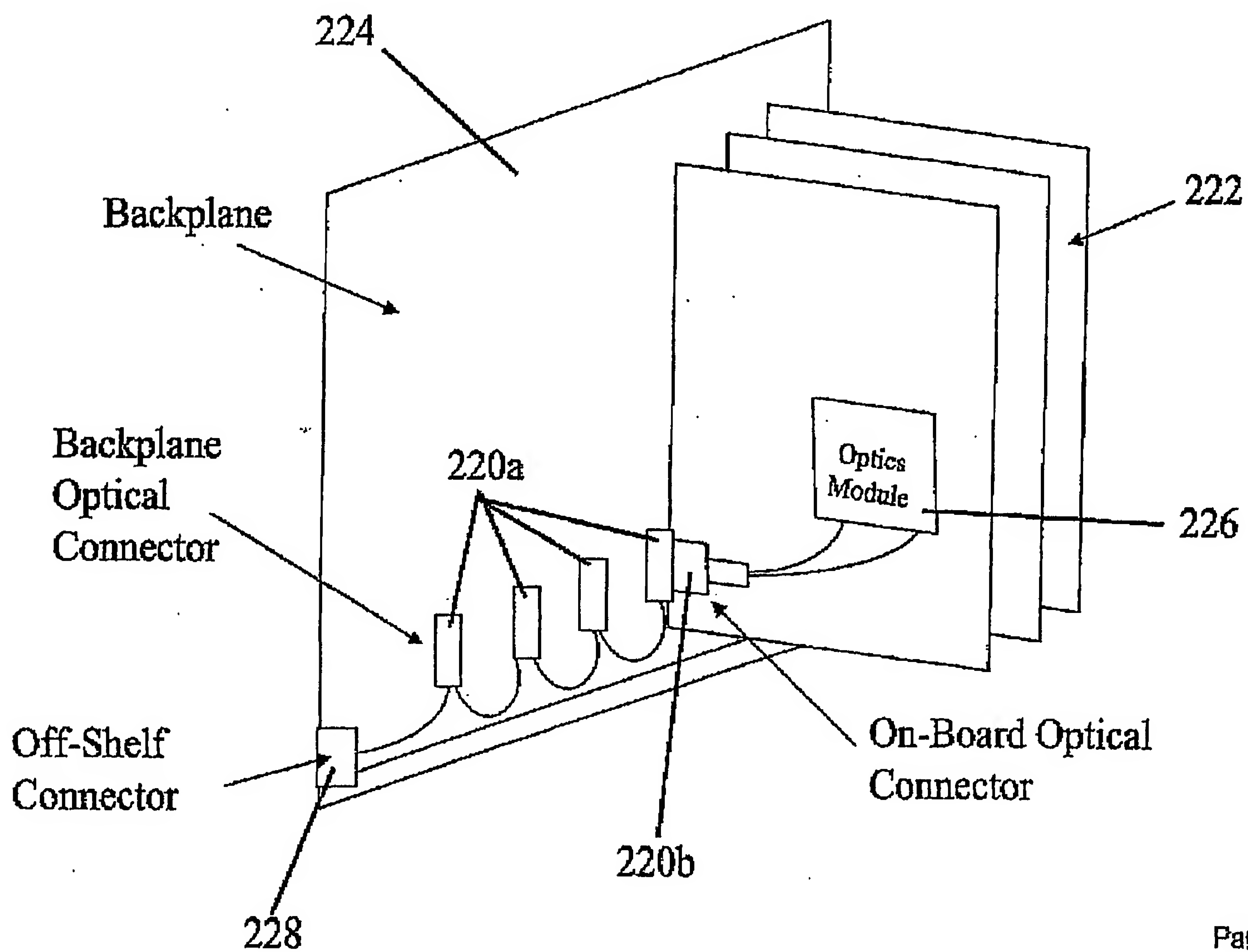

224
Backplane
222
Backplane
Optical
Connector
220a
Optics
Module
226
Off-Shelf
Connector
On-Board Optical
Connector
220b
228

FIG. 34a

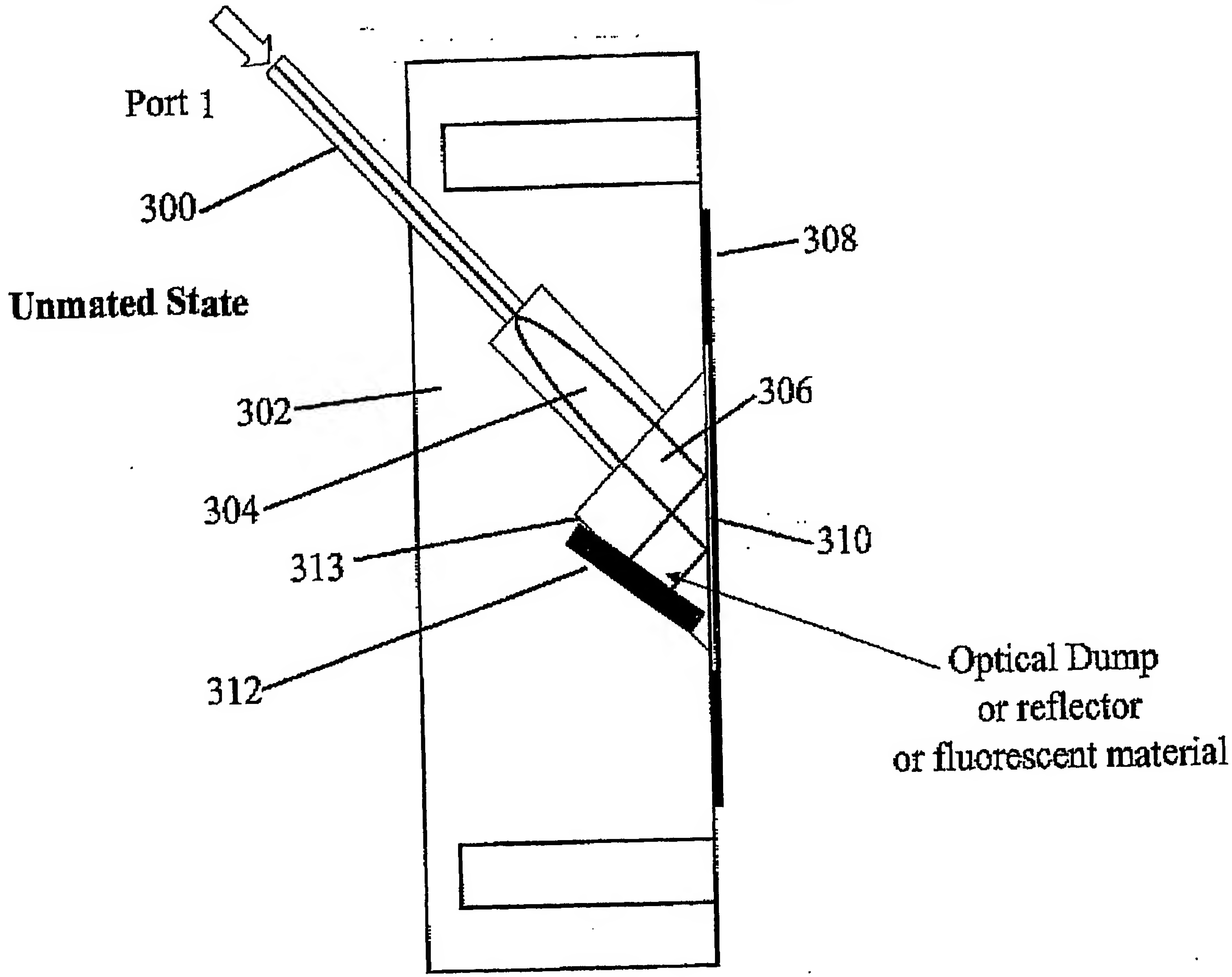

Port 1
300
Unmated State
302
304
313
312
308
306
310
Optical Dump
or reflector
or fluorescent material

FIG. 34b

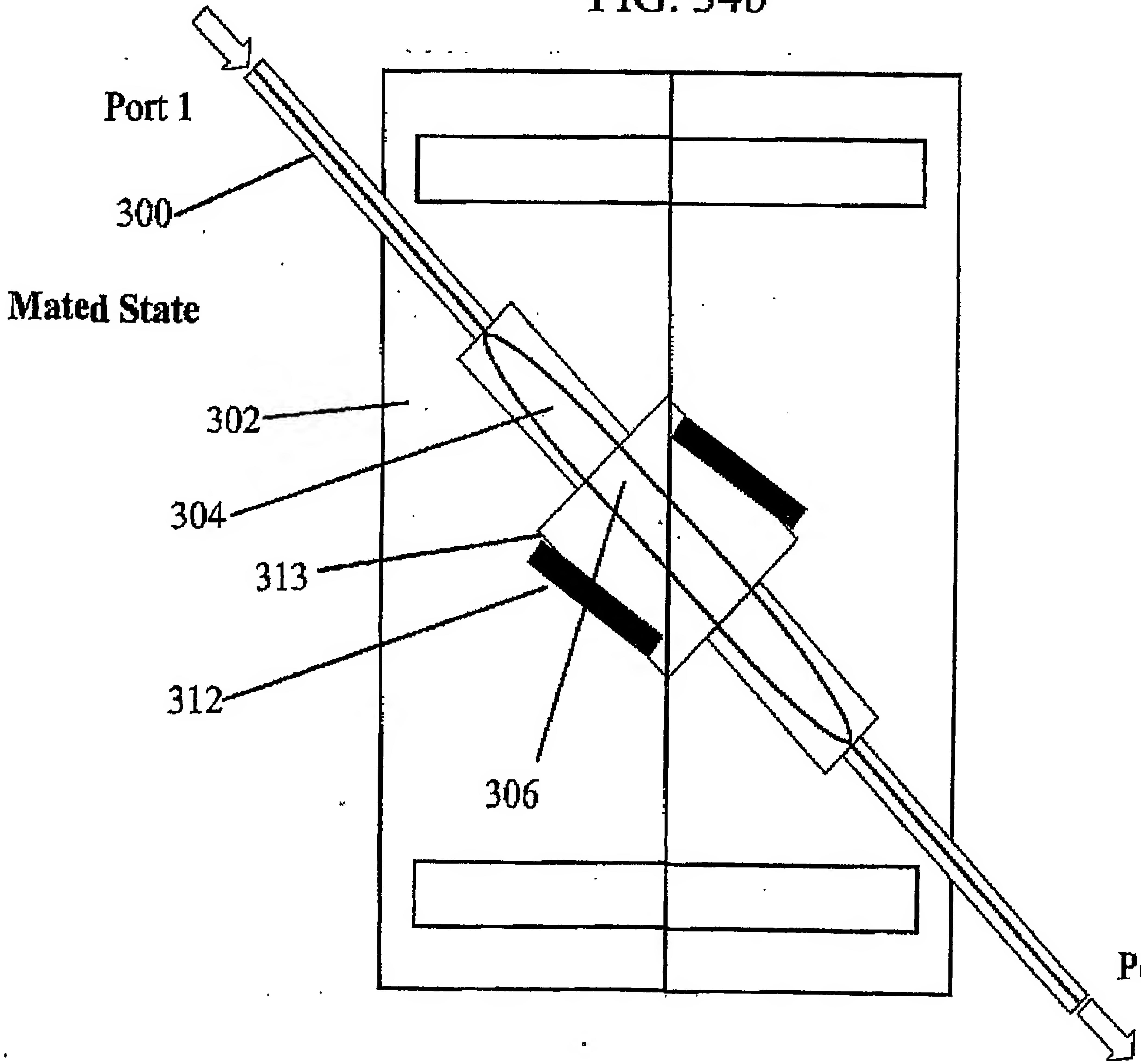


FIG. 35

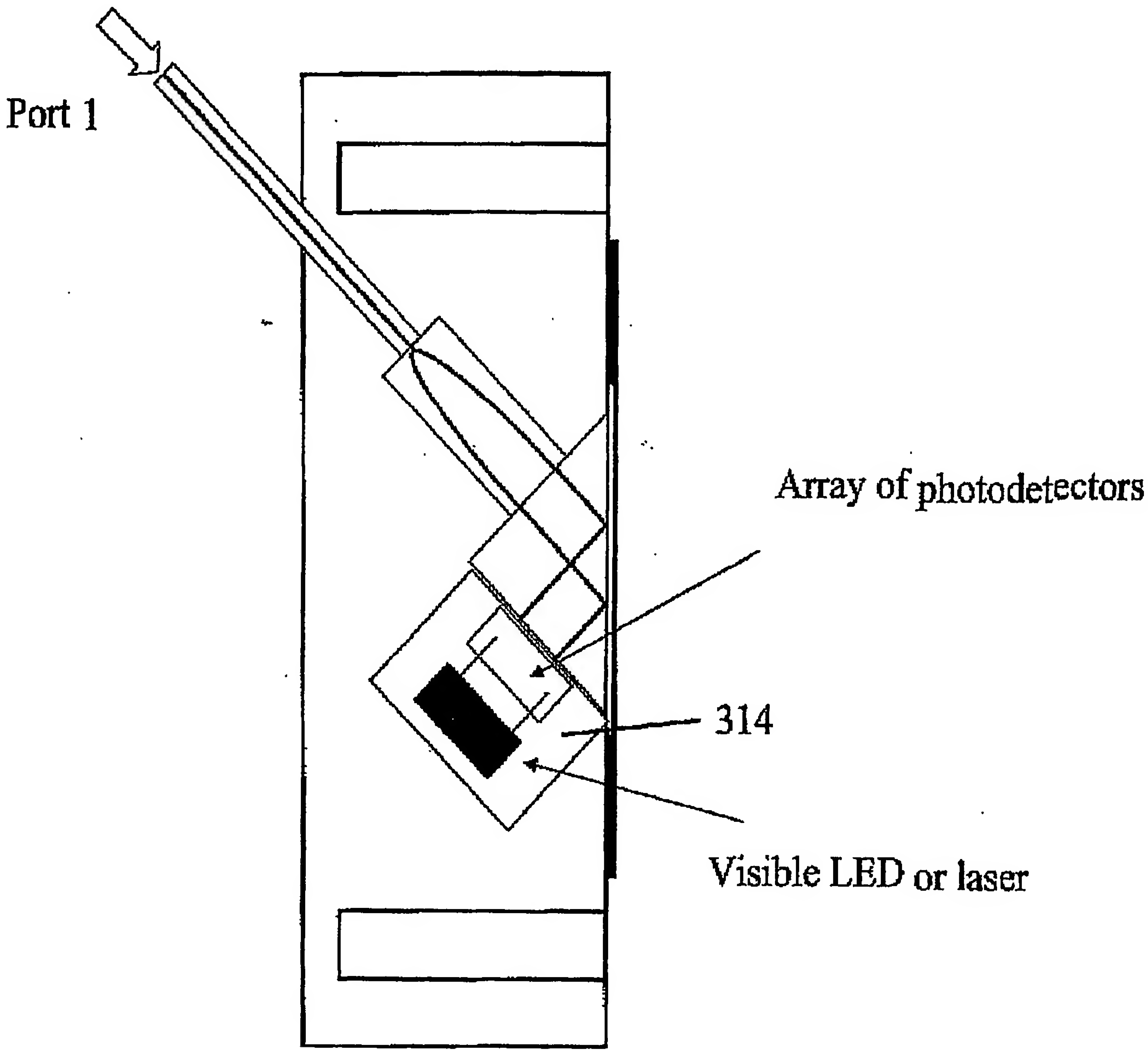


FIG. 36a

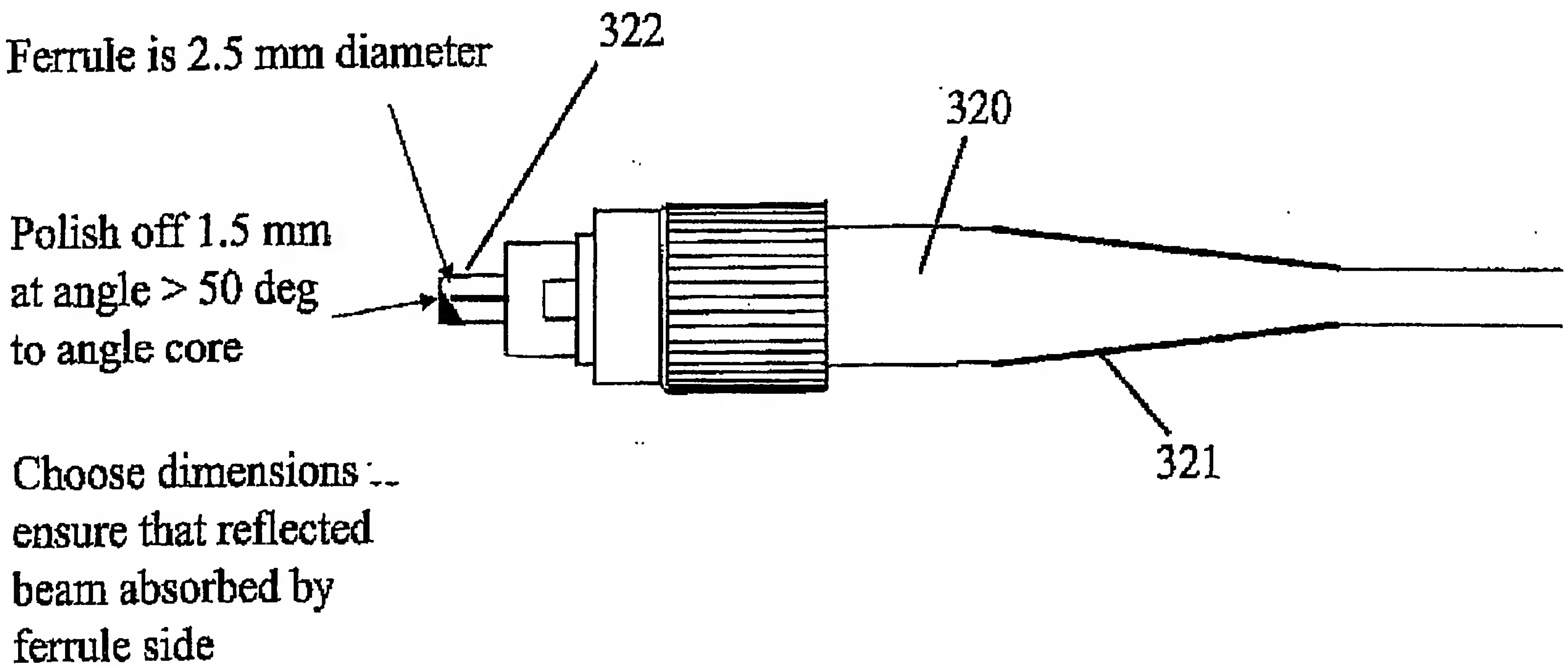

Ferrule is 2.5 mm diameter
322
320
Polish off 1.5 mm
at angle > 50 deg
to angle core
321
Choose dimensions --
ensure that reflected
beam absorbed by
ferrule side

FIG. 36b